JPL D-15390

Space Interferometry Mission

Technology Plan

15 January 1998

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EXECUTIVE SUMMARY

The Space Interferometry Mission (SIM), with a target launch date of June 2005, will be one of the premiere missions in the Astronomical Search for Origins (ASO) Program, National Aeronautics and Space Administration's (NASA) bold endeavor to understand the origins of the galaxies, of planetary systems around distant stars, and perhaps the origins of life itself. This adventure of discovery will be enabled by an explosive growth of innovative technology, as exciting in its own right as the underlying scientific quest.

Over the past several years a consensus has formed around the idea that space based optical interferometers operating in the visible and infrared wavebands represent the next great leap forward in astronomy and astrophysics. Interferometry is the only known method to significantly improve (by orders of magnitude) the angular resolution of current astronomical telescopes and thereby meet several key scientific goals of the 21st century: measurement of stellar diameters, resolution of close binaries, detection, imaging, and spectroscopy of extra-solar planets, and the precise measurement of galactic and cosmic distance scales. Interferometers lend themselves to space application due to their extremely efficient use of weight and volume to achieve the goals of high resolution, high sensitivity imaging and astrometry. SIM will mark NASA's first scientific use of this revolutionary observing technique in space. If it succeeds, it will presage the flight of the Terrestrial Planet Finder (TPF) and other larger and more ambitious Origins interferometers.

It is not surprising that such a huge step forward in observational power requires a concomitant leap in technological sophistication. SIM indeed drives the state-of-the-art in optomechanical and optoelectronic systems as well as presenting daunting challenges in precise stabilization of lightweight deployable structures and coordinated computer control of numerous optical surfaces. In this sense it very much embodies the principles of the Origins program -- to couple breakthrough science with breakthrough technology in the service of both a fuller knowledge of our universe and a richer technological landscape that helps preserve our nation's preeminence as a force for global innovation. In this regard technology has become an important end-in-itself for NASA's Origins missions.

NASA is prepared to take on greater risk with respect to the incorporation of new technologies in its space science missions but not to the point of recklessness. Hence, NASA's Office of Space Science has made it clear that technology readiness must be unambiguously established prior to commitment to a new start for any of its ambitious new missions. This is stated explicitly in the letter from NASA to Jet Propulsion Laboratory (JPL) which authorized SIM to enter Phase A at the beginning of fiscal 1998.

This Technology Plan represents the blueprint for completing the job, begun more than a decade ago, of building the technology necessary to make SIM a reality. It lays out the technical challenges and the approach to meeting those challenges. It details the development of specific hardware and software, as well as the test environments required to demonstrate that the hardware and software works together as an integrated whole. Successful implementation of this plan, with a target completion date of end of fiscal 2000, will place NASA in a position to proceed with the development of the SIM flight system, confident that it will return the promised science and do so within the allocated budget.

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1. INTRODUCTION AND BACKGROUND

1.1 Purpose and Scope

The purpose of the Space Interferometry Mission (SIM) Technology Plan is to document the course of action intended to establish technology readiness to implement the SIM. The Plan describes the mutual understanding between the Interferometry Technology Program (ITP) of the Technology and Applications Programs Directorate and the SIM Project of the Space and Earth Science Programs Directorate for the provision of required technology prior to the start of Project Phase C/D.

The scope of the plan encompasses the technology development objectives, the technology development approach, and a summary-level implementation plan that will result in the accomplishment of the objectives. The implementation plan includes:

(a) A description of the content and flow of the work;
(b) Assumptions as to funding, personnel, facilities, and other applicable resources;
(c) Plans for industry involvement and partnerships;
(d) A Work Breakdown Structure (WBS);
(e) A master schedule per the WBS;
(f) Cost and workforce requirements per the WBS;
(g) Milestones and deliverables per the WBS;
(h) A management plan that includes an organization chart, a statement of roles and responsibilities, plans for reviews and reporting, a risk management plan, and a reserve policy.

A greater level of detail as to the technology program implementation can be found in the individual subsystem Task Implementation Plans (TIPs), which will be generated as companions to this document.

This plan will be updated on an annual basis. Any formal revisions to the plan require the same approvals required by this version.

1.2 Relationship to Technology Development for Other Missions

The SIM Technology Plan is a stand-alone document that details the effort to be pursued by ITP in order to establish technology readiness for SIM.

The New Millennium Program (NMP) Deep Space-3 (DS-3) Separated Spacecraft Interferometer, the Keck Interferometer, and the Next Generation Space Telescope (NGST) are other missions that can be expected to benefit from ITP development efforts. At this point in time it is anticipated that any interdependencies between SIM technology (documented in this plan) and DS-3, Keck Interferometer, and NGST technology will be documented in memoranda of understanding.

1.3 Applicable Documents

(a) Project Systems Requirements Document (PSRD), version 1.1
(b) SIM Instrument System Requirements Document (ISRD), version 1.0
(c) Origins Technology Roadmap, Version 1, April 1997
(d) SIM Subsystem Task Implementation Plans (TIPs)
(e) Technology Plan for Space Interferometry Missions, July 1995
(f) Technology for Space Optical Interferometry, paper No. AIAA95-0825, January 1995

Documents 1.3 (a) and (b) present the technical requirements for the SIM flight system, to which the technological developments must be responsive. Document 1.3 (c) denotes this plan’s placement within the context of the overall Origins technology development effort. Documents 1.3 (e) and (f) present background on the historical development of space interferometry technology dating back to the late 1980’s.

1.4 SIM Mission Description

1.4.1 Mission Objectives and Reference Mission Design

The major scientific and technological objectives of the Space Interferometry Mission are:

(a) Search for other planetary systems
(b) Calibration of distances and ages in the universe
(c) Study of dynamics and evolution of stars and star clusters in our galaxy
(d) Study of dynamics and evolution of active galactic nuclei
(e) Study of the structure of circumstellar disks
(f) Serve as technology precursor to the Terrestrial Planet Finder (TPF) Mission

The current reference mission concept calls for SIM to be an optical interferometer operating in Earth orbit. The SIM spacecraft will be launched into a near-polar, circular, Sun-synchronous terminator orbit by a Delta-II 7920 launch vehicle in the year 2005. An option for an Earth-trailing 1 AU orbit is also under study.

The baseline SIM orbit is a terminator orbit with an altitude of 900 km, an inclination of 99 degrees, and a period of 103 minutes. The orbital plane will remain nearly perpendicular to the Sun-Earth line, requiring a precession rate slightly less than 1 degree per day around the Earth as the Earth orbits about the Sun (360 degrees in 365 days). This is accomplished without the use of a propulsion system by placing the spacecraft in an orbit with the proper altitude, eccentricity, and inclination such that the desired precession rate is achieved utilizing the gravitational effect of the Earth's oblateness. In this orbit the spacecraft will receive relatively uniform solar illumination within each orbit and throughout the year, resulting in a more benign thermal environment and fewer occultations (the spacecraft's solar cells stop producing power during occultations). The spacecraft will experience occultations on less than 100 days of the year, with a maximum duration of 20 minutes per orbit.

Following orbit insertion, the two hinged siderostat booms will be deployed, the metrology mast rotated up and extended, and the external metrology tetrahedron on the end of the mast deployed. Spacecraft systems will be checked out and tracking data collected to precisely determine the actual orbit achieved. After a period of several days to allow dispersion of any contaminants, the optical covers will be opened. Check-out and calibration of the interferometer will then commence and continue for several months. From the end of this calibration period through the year 2010, the SIM interferometer will perform nearly continuous science observations over the entire celestial sphere.

Key Reference Mission Parameters (12/97)

- Orbit 900 km, Sun-synchronous
- Orbit Period 103 min.
- Launch Vehicle Delta-II 7920
- Mass (margin) 2212 kg (26%)
- Power (margin) 968 W (42%)
- Position/Velocity Global Positioning System (GPS) (4 mm/sec)
- Lifetime 5 years

1.4.2 Reference Interferometer Instrument Design

The SIM design (**Figure 1-1**) uses three collinear interferometers mounted on the 10-meter long siderostat boom. Each interferometer collects light from two siderostats (telescopes) and combines them in the main optical boom. Two of the three interferometers will acquire fringes on bright guide stars in order to make highly precise measurements of the spacecraft attitude. The third interferometer will observe the science targets and measure the target positions with respect to an astrometric grid of some 4000 stars evenly distributed around the celestial sphere.

Since the science object will typically be dim (18–20 mag), the attitude information from the two guide interferometers will be used to point the third (science) interferometer and acquire fringes. Using this "feedforward" technique, along with the absence of atmospheric disturbances, will allow SIM to rapidly achieve its desired accuracy in position measurements for a single observational period (Note that this requires precise instrument attitude knowledge, NOT precise attitude control).

An external metrology system measures the three baseline vectors (i.e., the distances and directions between the siderostat primary mirrors) from a common reference tetrahedron, monitoring minute changes in the baseline lengths and orientations. This measurement along with fringe position information, is used to determine the angular separation between stars at the microarcsecond level.

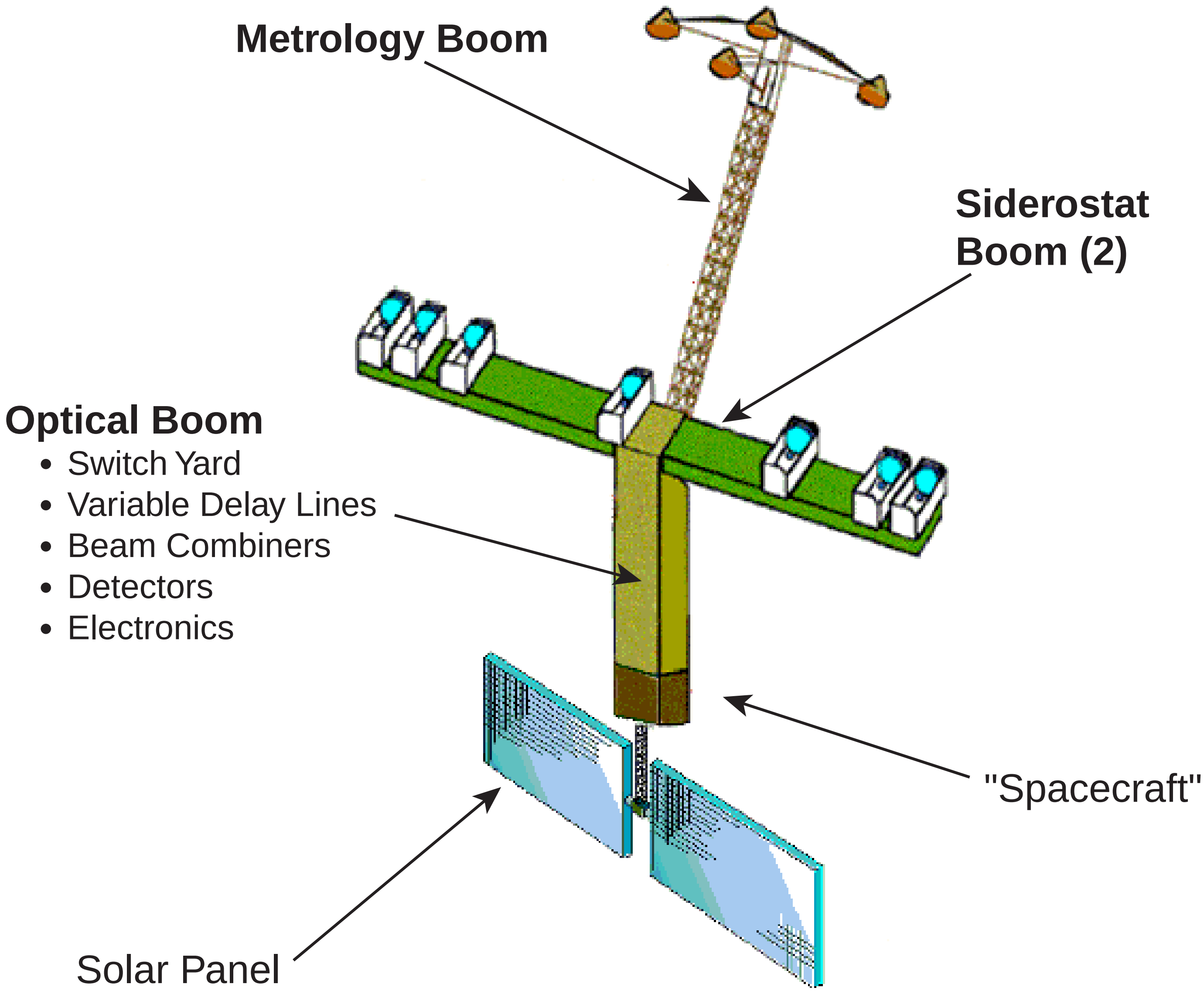


Figure 1-1. SIM Reference Mission Schematic Drawing

1.4.2.1 Making a Measurement

The SIM interferometer is based on an architecture derived from a series of ground-based interferometers: Mark III, Palomar Testbed Interferometer, and the Keck Interferometer. **Figure 1-2** illustrates how SIM makes its measurements. Starlight is collected by siderostats located at the ends of the interferometer and redirected to a beam combiner using a series of fold mirrors. The path difference between the two arms of the interferometer must be equal to within a few microns in order to produce a white light fringe signal. A movable delay line is used to add optical path in one arm of the interferometer to match the optical delays in the two arms of the interferometer. An internal metrology beam is used to measure the position of the white light fringe. An external metrology system is used to determine the location of each siderostat and measure the orientation and the length of the baseline vector. For astrometry the quantity of interest is the angle, θ, between the star and the baseline vector and is given by the equation:

$$x = B \cos(\theta) + c$$

where x is the measured fringe position, B is the baseline length, and c is an instrument offset that can be calibrated out.

For synthesis imaging measurements, the fringe position gives the phase at a particular baseline length and orientation (u-v point), and a measurement of the white light fringe visibility gives the amplitude. Amplitude and phase data measured at a large number of u-v points can be synthesized to form an image using techniques developed for radio interferometers that effectively compute the reverse Fourier transform.

1.4.2.2 Subsystems of the SIM Interferometer

Starlight Subsystem: The Starlight subsystem is responsible for delivering the opto-mechanical hardware necessary to collect starlight and form white light fringes. The components in this subsystem include:

(a) siderostat mirrors,
(b) beam compressor
(c) steering/alignment mirrors
(d) delay lines
(e) beam combiners
(f) detector/cameras

This subsystem has a large number of mechanisms and high-precision optics. Prototypes of these subsystem hardware units are being built and tested in ITP.

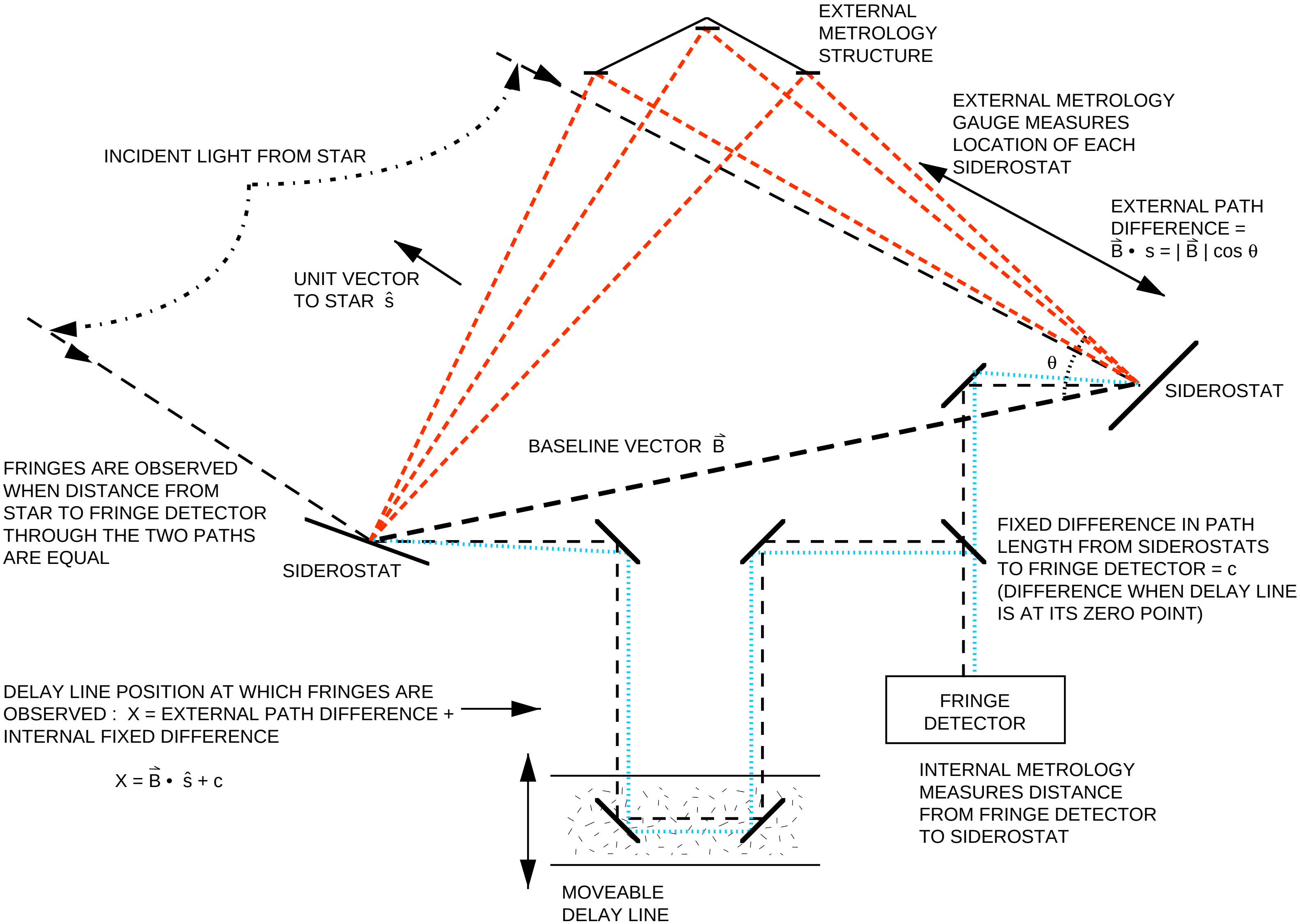


Figure 1-2. SIM Optical Paths (Starlight Path in black, external metrology in red, internal metrology in blue)

Metrology Subsystem: The Metrology subsystem is responsible for delivering the opto-electronic hardware necessary to measure the interferometer components to subnanometer accuracy. The components in this subsystem include

(a) lasers
(b) frequency shifter/modulators
(c) frequency stabilizer
(d) fiberoptics distribution
(e) beam launchers
(f) optical fiducials

Like the Starlight subsystem, a number of these components are currently being prototyped by the Interferometer Technology Program. In addition, a series of ground testbeds are being built to demonstrate the measurement capability of the metrology subsystems in a vacuum.

Interferometer Real-Time Control Subsystem: The Interferometer Real-Time Control (IRTC) subsystem is responsible for delivering the interferometer computer, electronics, and software. IRTC will also develop the algorithms needed to operate the pointing and path length control loops. In support of control algorithm development, the instrument system engineering function will develop integrated models of SIM that combine optical, structural, and control disciplines. Modeling will be done primarily with the Integrated Modeling of Optical Systems (IMOS) tool and be supplemented with traditional tools such as Code V, NASTRAN, and Thermal Radiation Analyzer System (TRASYS)/Systems Improved Numerical Difference Analyzer and Fluid Integrator (SINDA).

Precision Structure Subsystem: The SIM Precision Structure houses the hardware delivered by the three subsystems described above. The reference design structure consists of a main optics boom containing the delay lines, beam combiners, cameras, and spacecraft subsystems. Two collector booms holding the siderostat bays are deployed to give a 10 meter maximum baseline length. A metrology boom is also deployed and will hold the metrology reference tetrahedron and beam launchers for the external metrology subsystem. The Precision Structure Subsystem is also responsible for thermal control and engineering for the entire flight system.

Interferometer Integration and Test Subsystem: The Interferometer Integration and Test (II&T) subsystem will integrate the hardware and software delivered by the subsystems described above and demonstrate that SIM meets its functional, performance and environmental requirements. Since optical interferometers are relatively new and somewhat complex, a series of ground testbeds, beginning with the Microprecision Inferometer (MPI) testbed will develop the techniques and capability to integrate and test flight interferometers in less time and at a low cost.

1.4.3 Major Technical Challenges

Successful development of SIM requires that three grand technological challenges be met and overcome:

- nanometer level control and stabilization of optical element on a lightweight flexible structure
- subnanometer level sensing of optical-element-relative positions over meters of separation distance
- overall instrument complexity and the implications for interferometer integration and test and autonomous on-orbit operation.

These flow from the fundamental scientific and technological objectives of the mission, as illustrated in **Figure 1-3**.

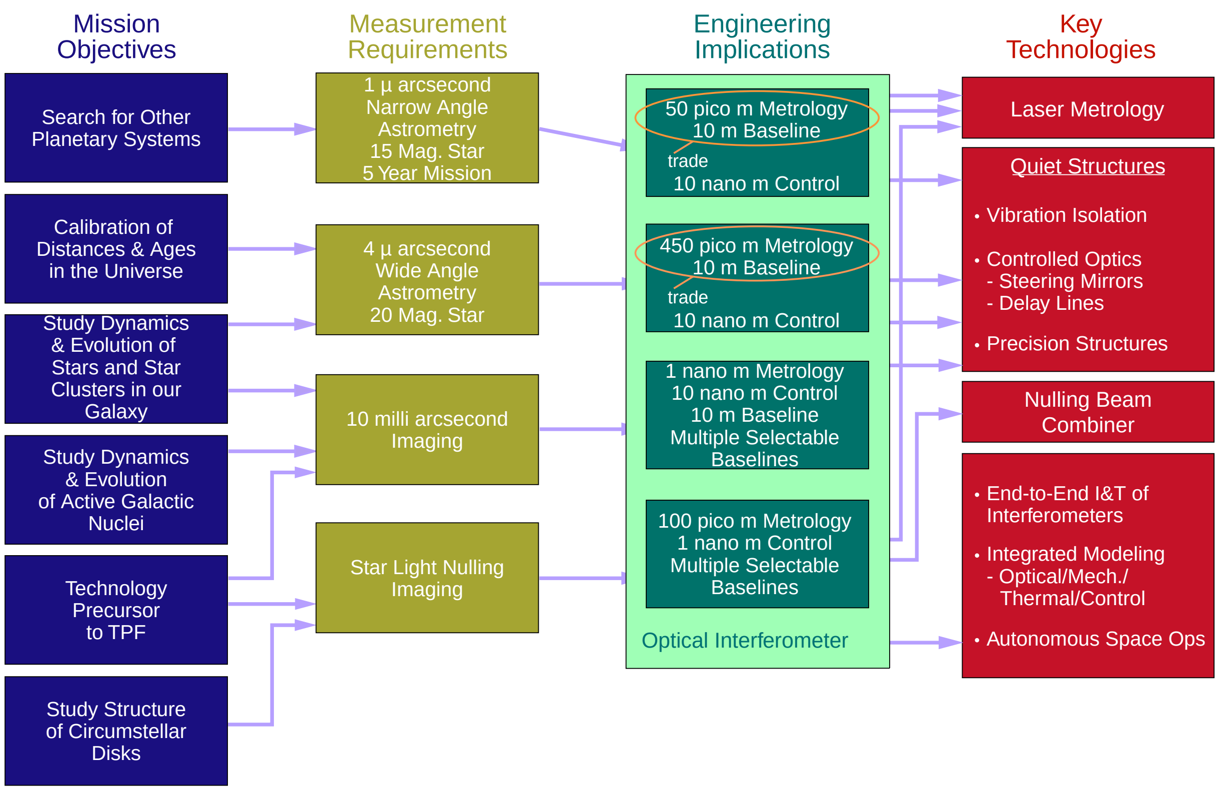


Figure 1-3. SIM Technology Requirements Flowdown

The need for nanometer control is driven by requirements on fringe visibility for astrometry and imaging as well as by the requirement for 10^4 starlight nulling. The nulling requirement is the more stringent, necessitating 1 nanometer RMS optical path difference (OPD) control over a broad vibratory frequency range. Fringe visibility requirements translate into the need for 10 nanometer RMS OPD control at frequencies above the fringe detector frame rate of approximately 1 kHz, and more relaxed requirements at lower vibration frequencies.

The picometer regime metrology requirements flow directly from the principal astrometry science requirements. In order to make a 4 microarcsecond angular measurement between two stars using a 10 meter baseline triple interferometer, a relative measurement of baseline positions to 100 picometers is required.

The complexity of an interferometer, with all its moving parts and control systems, is the price that must be paid for stepping beyond the paradigm of rigid monolithic telescopes as built since the days of Galileo. SIM will have to use active feedback control for at least 50 optical degrees of freedom. Another 80 degrees of freedom will need to be controlled in open loop fashion. Additional degrees of freedom will require articulation at least once for initial deployment and instrument alignment. Because of its complexity, the development of real-time software capable of autonomously operating SIM assumes great importance. New and creative integration and test methods will also be required to enable development of the instrument at an affordable cost.

The suite of new technologies that must be developed to enable SIM is depicted in **Figure 1-4**.

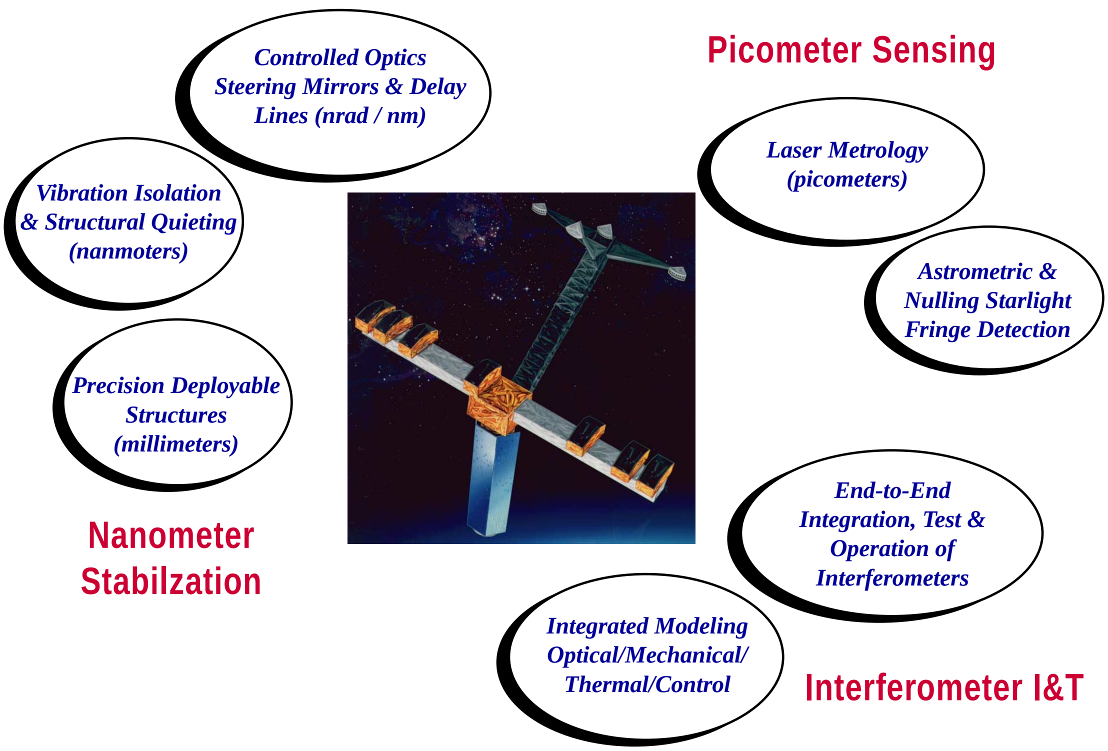


Figure 1-4. Key Technologies for SIM

These technologies, and the approach taken to their development, will be discussed in detail in Sections 2 and 3.

1.4.4 Project Schedule and Budget

The technology for SIM must be developed on a schedule consistent with the overall project schedule (see **Figure 1-5**).

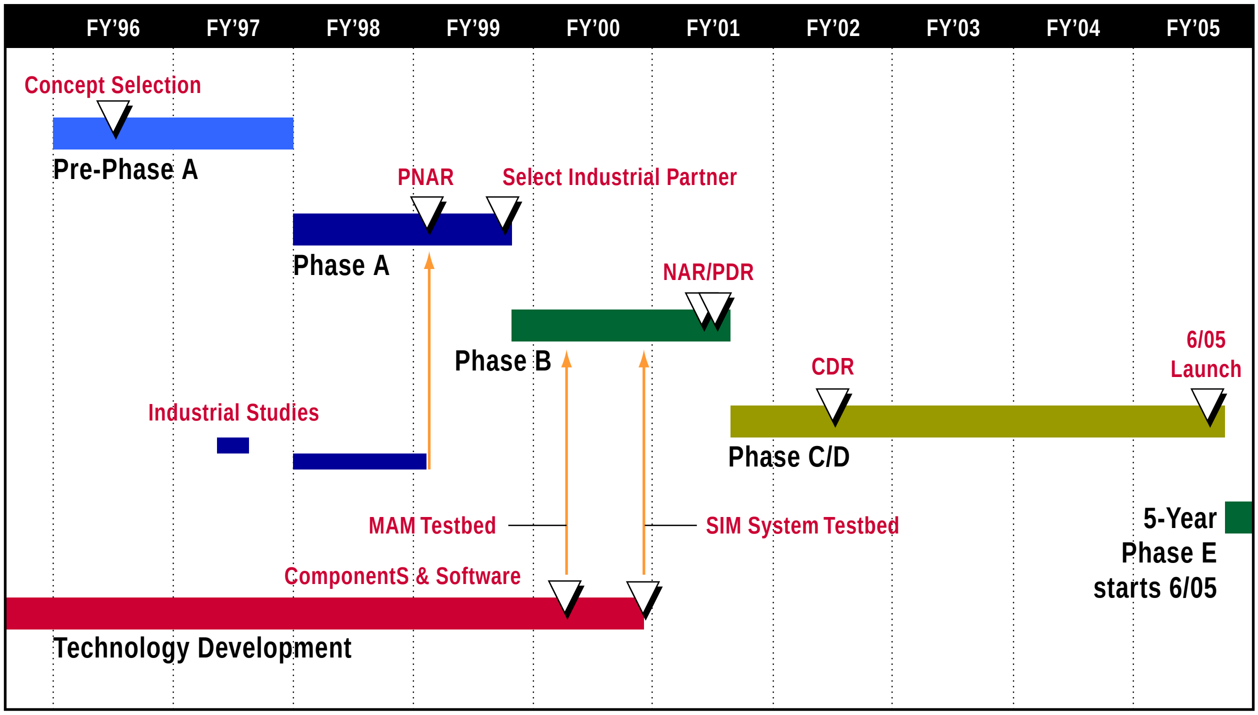


Figure 1-5. Top Level SIM Project Schedule

Technology readiness will be established by the end of fiscal year 2000, which implies that the preponderance of SIM's technical risk will have been retired prior to its Non-Advocate Review (NAR) and Preliminary Design Review (PDR), scheduled for fiscal year 2001.

The budget required to execute the technology development program for SIM as well as the overall SIM Project budget appear in **Table 1-1**.

Table 1-1. SIM Project and Technology Development Budget

	Pre-Phase A		Phase A		Phase B		Phase C/D				
	Previous	FY '97	FY '98	FY '99	FY '00	FY '01	FY '02	FY '03	FY '04	FY '05	Real Year Total
Other Applicable Prior Tech. Investment	21.0										21.0
Tech. Development and Ground Testbed	6.5	9.0	21.0	16.0	13.5						66.0
Technology Flight Demonstration			0.0	0.0	0.0	0.0					0.0
Pre-Phase A Studies	2.5	4.0									6.5
Phase A			14.8	15.0							29.8
Phase B					27.2	27.0					54.2
Phase C/D						51.0	105.5	129.8	103.4	91.3	481.0
Total JPL	30.0	13.0	35.8	31.0	40.7	78.0	105.5	129.8	103.4	91.3	658.5
NASA Sub Total	30.8	13.3	36.7	31.8	41.7	80.0	108.1	133.0	106.0	93.6	675.0
Guideline			36.7	31.8	41.7	80.0	108.0	133.1	106.1		
Delta			0.0	0.0	0.0	-0.1	0.1	-0.1	-0.1		
Launch Vehicle								17.1	32.2	22.8	72.1
NASA Total	30.8	13.3	36.7	31.8	41.7	80.0	108.1	150.1	138.2	116.4	747.1

It should be noted that NASA investment in interferometry technology prior to fiscal year 1996, dating back to the late 1980's, amounts to an additional $21M above and beyond the $66.0M specifically targeted at SIM.

2. TECHNOLOGY DEVELOPMENT OBJECTIVES AND APPROACH

2.1 Technology Development Objectives

The overriding objective of the technology program is to establish technology readiness for SIM. For hardware products, technology readiness is defined as:

(a) The establishment of feasibility through the development of breadboard (i.e., proof-of-concept) hardware that meets flowed-down component performance requirements
(b) Demonstration of practicality by qualifying brassboard (i.e., functionality at relevant environment) designs that meet performance as well as space, environmental, and lifetime requirements
(c) Verifying implementability by demonstrating (in technology testbeds) that the component hardware is capable of being integrated into subsystems and systems that meet overall functional and performance objectives

For software products, technology readiness is defined as:

(a) The establishment of feasibility through the development of breadboard (i.e., proof-of-concept) software that meets flowed-down performance requirements
(b) Demonstration of practicality via the development of prototype software meeting performance as well as space processor derived constrains
(c) Verifying implementability by demonstrating (in technology testbeds) that the software is capable of being integrated into subsystems and systems that meet overall functional and performance objectives

2.1.1 Picometer Sensing

The technology program will establish technology readiness to implement—in flight hardware—a SIM laser metrology system that meets the following requirements:

(a) 1-D relative point-to-point measurement accuracy of 7 picometers
(b) 3-D relative baseline-to-baseline measurement accuracy of 50 picometers for narrow angle astrometry
(c) 3-D relative baseline-to-baseline measurement accuracy of 450 picometers for wide angle astrometry
(d) 3-D absolute measurement of an entire metrology truss to 5 microns accuracy
(e) Capable of being configured such that 4 µas stellar position measurments are enabled

2.1.2 Nanometer Stabilization

The technology program will establish technology readiness to implement—in flight hardware—SIM vibration attentuation systems that meet the following requirements:

(a) 1 nanometer OPD stability (over 1 second integration times) of a single baseline
(b) 10 nanometer OPD stability (over 30 second integration times) of the science baseline
(c) 150 nanoradian pointing stability (over 30 second integration times) in object space of the science interferometer beam train

Requirement (a) derives from the starlight nulling requirement. Requirements (b) and (c) derive from the need to maintain adequate fringe visibility of the science star interferometer during astrometry and imaging operations. Similar but less stringent stabilization requirements pertain to the guidestar interferometers.

2.1.3 Interferometer Integration, Test, and Autonomous Operation

The technology program will establish technology readiness to implement (in flight software) an autonomous, realtime interferometer control system capable of aligning and operating the SIM interferometer instrument within the operational constraints of SIM electronics systems.

The technology program will establish technology readiness to integrate and test the SIM flight instrument. The process for integrating a complex spacecraft subsystem is well established and has been proven on many interplanetary spacecraft, such as Galileo and Cassini. The methodology for integrating and testing a space interferometer, however, is not well known and must be developed. This is a major challenge for SIM.

Ground-based interferometers have been integrated successfully, but the unique challenges of space were not a consideration in those projects. The SIM instrument must be tested in the presence of gravity and air, yet the process must provide confidence that it will work in space at full performance. The flight software is highly complex and must operate autonomously. Therefore, the test program must be very thorough and stress the flight software to its limits. The technology program will develop a methodology for integrating and testing the SIM instrument. The major contributors to this process will be ground testbeds, modeling, and analysis.

2.2 Technology Development Approach

Fundamentally the approach taken to technology development is one of rapid prototyping of critcal hardware and software followed by integration into technology testbeds where critical interfaces can be validated, system level performance demonstrated, and integration and test procedures developed and verified. To some extent, due to the objective of completing the technology development by the end of fiscal year 2000, this will entail concurrent engineering (e.g., we will need to develop some hardware component brassboards in parallel with the development of the testbeds, dictating that breadboards of those components will be used in the testbeds rather than brassboards, which would be preferred).

This approach places the ground testbeds at the very heart of the technology development effort. It is in these testbeds that the technology products will be validated and technology readiness demonstrated. It is also in these testbeds that our engineering team will learn about what works and what does not when it comes to integrating and testing interferometers. The testbeds developed by the technology program are deliverables to the SIM Project for use throughout the project life cycle. Flight experiments will in general be undertaken only where the space environment is required to explore the relevant phenomenology.

It is important to note that in the final analysis the key deliverable from ITP to SIM is knowledge—knowledge of how to build interferometer parts and software that work and knowledge of how to integrate those parts and software into interferometer systems that work. This knowledge will be contained in the vessel that is the team of people who execute the SIM Technology Plan. Hence, this team constitutes a key ITP deliverable to SIM. It is in fact essential to the execution of this plan that ITP and SIM establish essentially a single team that executes the project Phase A/B at the same time that it executes the technology development effort. This team, complete with industrial and university support, will then move forward into Project Phase C/D with the knowledge it needs to implement SIM on schedule and within cost.

2.2.1 Component Hardware Development

Breadboards[1] and brassboards[2] of the new technology components required by SIM will be built and tested by the technology program. The objectives are threefold:

(a) mitigate technical, schedule, and cost risk associated with key hardware components early in the SIM project life cycle (when the cost of correcting problems is low)
(b) deliver necessary components to the technology integration testbeds
(c) transition the capability to manufacture the components to industry

Although the intent is that all SIM flight components will be built by industry, at this stage of the development cycle there are some components that JPL is uniquely suited to brassboard, others that will be subcontracted to vendors (through the normal competitive process), and still others that would be suited to a collaborative effort between JPL and industry. Collaborations are typically handled either through the Small Business Innovative Research (SBIR) Program (see Section 3.1.1 for a discussion of the SBIR Program), or through Technology Cooperation Agreements (TCA) where no funds change hands between JPL and its partner.

For each component to be brassboarded, whether it is built in-house, built in partnership with industry, or procured in a traditional manner, a series of performance and environmental tests will be conducted whose objective it is to qualify the component design as ready for space flight. A distinction is made between qualifying the design and qualifying the component itself. None of the brassboard components are destined for flight, and hence the qualification process will lack the formality (and cost) associated with flight hardware. Nevertheless, the qualification process will be quite rigorous with each component subjected to full functional, shock, random vibration, and thermal (and/or thermal/vacuum) testing. JPL quality assurance and reliability personnel will be included from the outset to ensure proper design and test procedures. (Note that only those components considered high risk will be built and tested as brassboards.)

Technology transfer of the brassboard components to industry will be accomplished through the use of brassboard hardware documents that contain requirements and design documentation, lessons learned from design and test, failure risk analysis, and additional qualification required of future units. These documents will be provided to industry along

1. Developments for proof-of-concept demonstrating functionality using off-the-shelf commercial parts.

2. Developments to demonstrate performance using best estimate of form, fit, and function, emphasizing design and performance test under relevant environmental conditions.

with the SIM detailed requirements for each flight component. Industry will be at liberty to bid for each component based upon optimal implementation of the existing design or a new design that better satisfies requirements. All procurements of SIM flight hardware components are expected to be competitive.

Progress in building and testing the required breadboard and brassboard hardware will be monitored using the component hardware metric charts depicted in **Figure 2-1**. The figure refers to 19 hardware components, each of which must be breadboarded and brassboarded.

2.2.2 Prototype Realtime Software Development

SIM will be required to operate with limited intervention from the ground and thus perform initial optical alignment, calibration, stellar target acquisition, angle tracking, fringe tracking, slew, continuous rotation for synthesis imaging, and other autonomous functions. Realtime software will play the central role in performing these functions. This software represents a significant technical challenge since it will have to operate a very complex instrument, run on a distributed set of computers, and control processes at timescales from milliseconds to days. As advanced systems demand increasingly sophisticated software, the portion of project cost (and associated schedule and cost risk) assigned to software begins to rival that of hardware. Hence, the technology program has placed the importance of realtime software development on a par with interferometer hardware development.

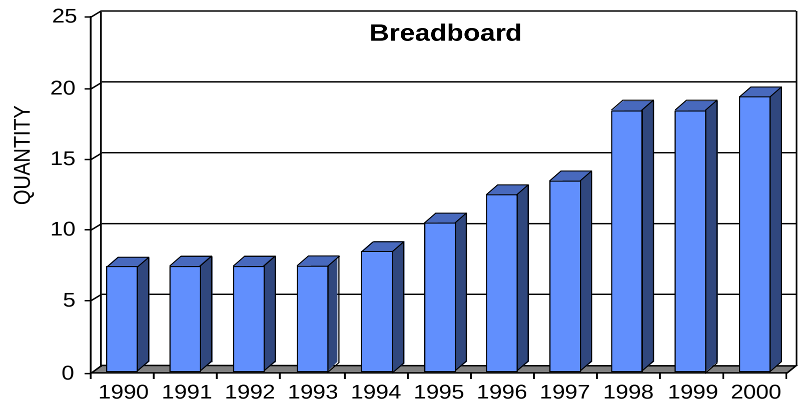
The approach to realtime software development is fully analagous to the development of component hardware via breadboards and brassboards. Breadboard software is regarded to be code that establishes the feasibility of performing a particular function. Brassboard software is a true prototype of flight software and demonstrates that the constraints imposed by the target flight processor can be met and that the code is efficient and maintainable. It is intended that the brassboard (or prototype) software developed under the technology program could actually be flown on SIM with only minor modification and upgrade required.

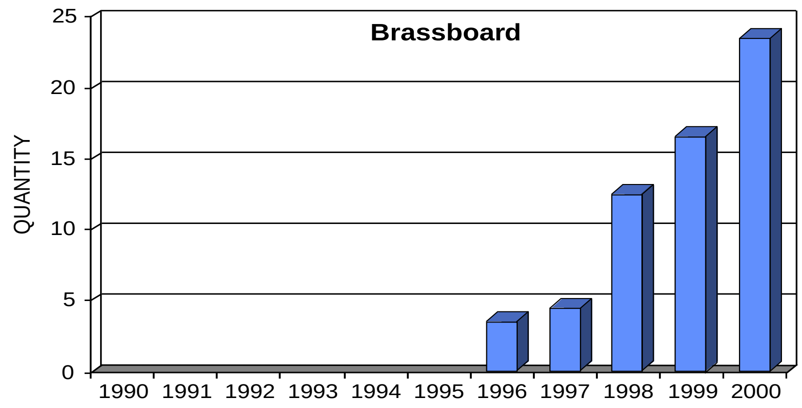
SIM breadboard software development is largely completed thanks to two ground interferometers that were built in the last five years—the Palomar Testbed Interferometer (PTI) and the MPI Testbed. The former is a fully functional 110 meter baseline system that has been in operation on Palomar Mountain since the summer of 1995. Built primarily as a technological precursor for the Keck Interferometer, it is also in active use taking science measurements. The MPI Testbed [also known as System Testbed 1 (STB-1)], as will be discussed later in this document, is a 7 meter, single baseline, lab emulation of a flight interferometer. It has been operational since late 1994. PTI and MPI share a significant amount of common realtime software and demonstrate the basic feasibility of automated interferometer operation.

STARLIGHT COMPONENTS
- **Siderostat**
- **Beam Compressor**
- **Fast-Steering Mechanism**
- **Alignment and Switchyard Mechanisms**
- **Adjustable Mirror Cell**
- **Astrometric Beam Combiner**
- **Nulling Beam Combiner**
- **Charged Coupled Detector**
- **Avalanche Photo Diode**
- **Optical Delay Line**

METROLOGY COMPONENTS
- **Laser**
- **Frequency Shifter**
- **Frequency Modulator**
- **Laser Stablizer**
- **Fiber Distribution System**
- **Beam Launcher**
- **Wide Angle Coner Cube**

PRECISION STRUCTURE COMPONENTS
- **Siderostat Bay**
- **Active Isolation**





NOTE: Some Components have multiple breadboards or brassboards

Figure 2-1. Component Hardware Development Progress Metric

The development of the SIM prototype (or brassboard) software will take place in an environment called the Realtime Interferometer Control Software Testbed (RICST). RICST will build the code, ultimately expected to exceed 70,000 lines, in a modular fashion and will make a series of incremental deliveries. This will greatly simplify the process of testing and debugging. The initial deliveries will be internal to the RICST team and will serve to validate the development approach and train the personnel. RICST testing will incorporate breadboard and brassboard hardware, allowing the software to be fully exercised by actually driving the relevant controlled components. Eventually, the RICST software will be delivered to integration testbeds (described below) where it will be used to operate complete interferometers like SIM. This process is expected to result in software that can be referred to as “protoflight”, i.e., ready for flight application with modest rework.

Progress in building and testing the required realtime software will be monitored using the software maturity metric charts depicted in **Figure 2-2**.

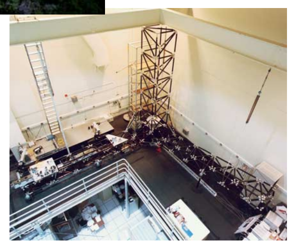
2.2.3 Integrated Modeling Tool Development

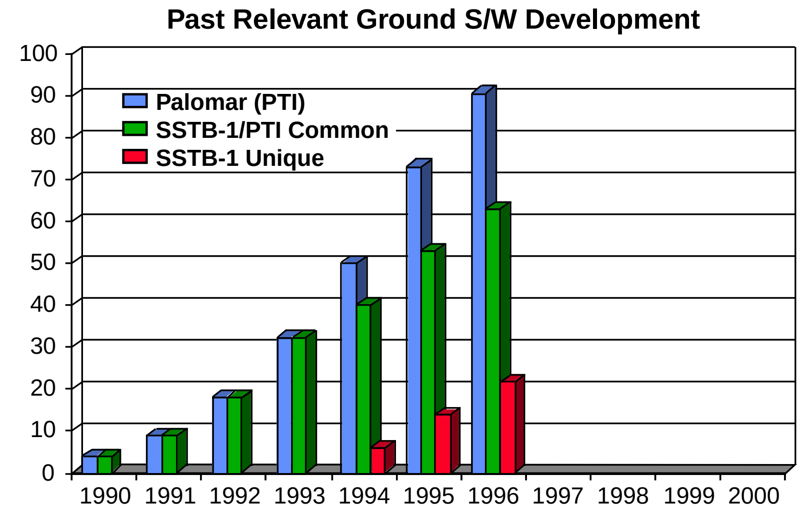
The challenges facing space interferometry do not lie exclusively in the province of developing component hardware and realtime control software. Work is also needed to advance the state-of-the-art in software tools for analysis and design. Existing analysis tools provide only limited capability for evaluation of spaceborne optical system designs. These tools determine optical performance from the geometry and material properties of the optical elements in the system, assuming only minor deviations from the nominal alignment and figure. They cannot evaluate the impact on optical performance from controlled/articulated optics, structural dynamics, and thermal response, which are important considerations for future interferometer missions. To investigate these critical relationships, a new analysis tool called IMOS has been under development. IMOS enables end-to-end modeling of complex optomechanical systems (including optics, controls, structural dynamics, and thermal analysis) in a single seat workstation computing environment. IMOS has been applied at JPL to the Hubble Space Telescope and the Space Infrared Telescope Facility (SIRTF), as well as virtually all the space interferometer designs that have been considered in recent years [e.g., SIM, Orbiting Stellar Interferometer (OSI), Interferometer Stellar Imaging System (ISIS), SONATA, Dilute Lens Interferometer (DLI), Focus Mission Interferometer FMI, MPI, Precision Optical Interferometer in Space (POINTS)].

IMOS is a collection of functions that operates in the MATLAB environment. Currently these functions perform structural modeling and analysis, thermal analysis and optical analysis (when used in conjunction with MACOS). IMOS also incorporates several graphics functions that enable viewing of structural assembly operations, structural deformations, and element optical layouts. The core modules are easily coupled in MATLAB, and can be extended by the user by writing his/her own MATLAB functions. Additional capabilities offered by the MATLAB toolboxes for control design, signal processing and optimization further enhance the versatility of IMOS. Several interface programs have also been developed for optical analysis (MACOS), thermal analysis (TRASYS and SINDA), and finite element modeling (NASTRAN). IMOS has a limited internal optical analysis capability, and as an alternative to using the SINDA program, there is also an internal function for solving the heat balance equation.

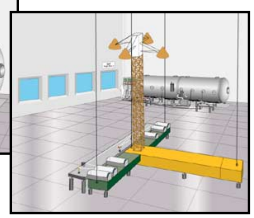
Palomar
Testbed
(PTI)

SIM System
Testbed
Version 1
(SSTB-1)



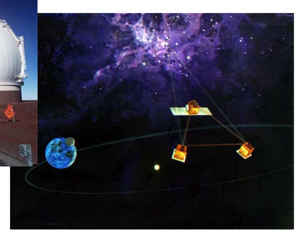


Microarcsecond
Metrology

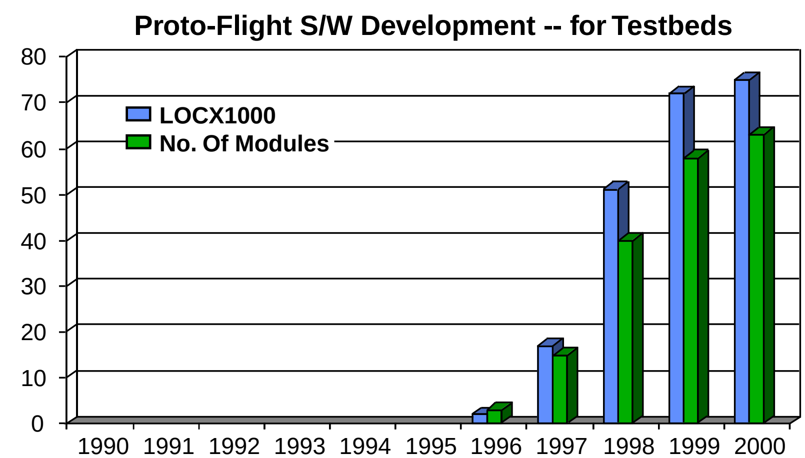


SIM System Testbed
Version 3

Keck Observatory



DS-3



- SIM flight S/W (70,000 LOC) will be an extensive reuse of the above S/W
  - Upgrade/modification only as necessary

Figure 2-2. Prototype Software Development Progress Metric

IMOS was originally created as a modeling tool to assist in the early design phases of multidisciplinary systems. In recent years IMOS has matured tremendously and has greatly increased its ability to address complex, many degree-of-freedom systems that are typical of the detail design phase. Currently IMOS is the baselined integrated modeling tool for the SIM project and NGST pre-project, and is also being adopted by their industry partners. Nevertheless, additional development resources will be devoted to IMOS to improve the performance and applicability of its constituent modules, to maintain effective configuration control of the software, to manage software upgrades with new code releases, and to properly document evolving capabilities with revised releases of the IMOS User Manual. The cost of providing these improvements to IMOS will be shared between the Interferometry Technology Program and JPL institutional funds.

2.2.4 Technology Integration and Validation Testing

In some sense, the hardware and software products delineated above comprise the full set of tools and parts that the SIM Project needs to design, build and operate the interferometer instrument. However, having developed all the pieces, one major task remains to be done—proving that the pieces fit together and work as an interferometer at the relevant levels of performance. This is the province of the ground testbeds.

The ground testbeds have several major objectives:

(a) prove that the hardware and software integrates and operates at full SIM complexity
(b) prove that the hardware and software integrates and operates at full SIM performance
(c) prove that the modeling tools can accurately predict SIM on-orbit performance
(d) train the SIM flight team in the intricacies of integrating and testing the flight instrument
(e) serve as troubleshooting tools during flight instrument integration, test, and flight ops
(f) serve as environments in which flight components can be tested as they become available
(g) serve as palpable symbols of technology readiness to implement SIM

It is not self-evident that all of the above objectives can be met on the ground or whether space demonstrations are also needed. Neither is it immediately clear whether meeting the objectives entails a single testbed or rather a set of testbeds, each targeting a particular portion of the demonstration space. To gain better insight into these questions a technology validation matrix was constructed (**Table 2-1**).

The matrix pits each technology area in need of validation against the pivitol attributes of the testing that must be conducted. Experimental attributes considered most important are:

(a) Can a technology be tested standalone on a test bench or is a testbed required?
(b) What testing needs to be done at full scale vs sub scale?
(c) What testing has to be done in vacuum?
(d) Are real stars required or will pseudostars do?
(e) What level of accuracy and precision is required for testing each technology?

Table 2-1. Technology Area vs. Validation Test Attributes

Technology Area	Stand Alone	Full Scale	Precision	Vacuum	Stars	Testbed Category
Picometer Metrology	No	No	picometers	Yes	multiple pseudo	microarcsec metrology
Nulling Focal Plane	Yes	No	picometers	Yes	pseudo	lab bench (vacuum)
Active Optics	No	Yes	nanometers	No	multiple pseudo	vibration attenuation
Vibration Isolation/ Suppression	No	Yes	nanometers	No	No	vibration attenuation
Precision Deploy-able Structures	No	Yes	nanometers	No	No	vibration attenuation (zero-g)
Integrated Modeling Tools	No	Yes	picometers	N/A	N/A	microarcsec metrology & vibration attenuation
S/W for Autono-mous Ops	No	No	N/A	No	pseudo	software integration & ground observatory
Science Data Processing	No	Yes	N/A	No	Yes	ground observatory
Techniques for I&T	No	Yes	nanometers picometers?	??	multiple pseudo	flight-like testbed

Cost is, of course, an important factor, and the guiding principle is—accomplish the technical risk reduction that is necessary but do so at the minimum cost. Corollaries to this principle are: don't test in space what you can test on the ground; don't test in vacuum what you can test in air; don't use flight quality hardware if breadboards will do; always ask, "could this test objective be accomplished for less money?"

Careful consideration of these factors has led us to adopt a technology validation program that involves four ground testbeds and two flight experiments. The flight experiments are both aimed at resolving the issue of the microdynamics of precision deployable structures. The rationale for going to space is that it is not possible to conclusively prove that structures which contain hinges and latches and joints, and hence have the potential to exhibit stick-slip behavior, will perform in zero-g in as linear a manner as they perform in 1-g. An overview of these flight experiments, dubbed Interferometry Program Experiments (IPEX) 1&2, is given below.

The four ground testbeds are the evolutionary SIM STB-1, 2, 3), the Microarcsecond Metrology (MAM) Testbed, the PTI, and the RICST. This particular delineation of the ground testbed effort derives from the technology validation matrix and the recognition that one major subset of the technologies can be tested in air at nanometer precision and at full scale, while another subset must be tested in vacuum at picometer precision but at sub-scale.

The first set of technologies, i.e., those associated with vibration attenuation, is grouped into the STB-1, 2, 3. The second, i.e., the laser metrology technologies, is assigned to the MAM Testbed. PTI, an operational ground based interferometer observatory, is uniquely capable of viewing real stars, which is necessary to validate the science data processing software. It is perhaps an overstatement to define RICST as a testbed. The primary function of RICST, as discussed above, is the development of prototype software and the delivery of that code to MAM and STB (where the it is validation-tested). However, RICST is also considered a testbed in its own right, in that each software module developed in RICST will be tested in the RICST environment with benchtop hardware in the loop before delivery to MAM and/or STB.

The interrelation of these testbeds with the other elements of the technology program and the flow of hardware components and software to the testbeds and ultimately, SIM, is illustrated in **Figure 2-3**.

2.2.4.1 Ground Testbeds

The testbeds are described briefly below.

The specific risk reduction objectives of each of the SIM testbeds is displayed in tabular form in **Table 2-2**.

Table 2-2. Testbed Objectives and Fidelity

Testbed	Primary Objective	Secondary Objective	Fidelity
STB-1	- Vib attenuation to 1 nm for guide int - Modeling tool verify	- Tours - Training for STB-2, 3	- Breadboard H/W - Breadboard S/W - Full scale
STB-2	- Fringe & angle feed forward from guide to science int @ 10 nm - Modeling tool verify	- Tours - Training for STB-3 - Moderate complex operation	- Bread/Brass H/W - Bread/Brass S/W - Full scale
STB-3	- Full complexity ops - Training for SIM I&T - SIM H/W staging/test - Mission ops trouble shooting	- Tours - Vib attenuation to 1, 10 nm with dynamic fidelity - Modeling tool verify	- Brass/Bread H/W - Brassboard S/W - Full scale - HiFi configuration - Full complexity
MAM	- Prove 50 pm 3-D gauges give µ-arcsec astrometry - Modeling tool verify	- Tours - Training for SIM metrology	- Breadboard H/W - Brassboard S/W
RICST	- Develop brassboard S/W	- Training for SIM Flt S/W - 1 B/L bench test	- Brassboard H/W - Brassboard S/W
PTI	- Keck int precursor - Science	- Tours - Dev data proc S/W	- Breadboard H/W - Breadboard S/W

The table also gives a sense of the maturity level of the hardware and software utilized in each testbed.

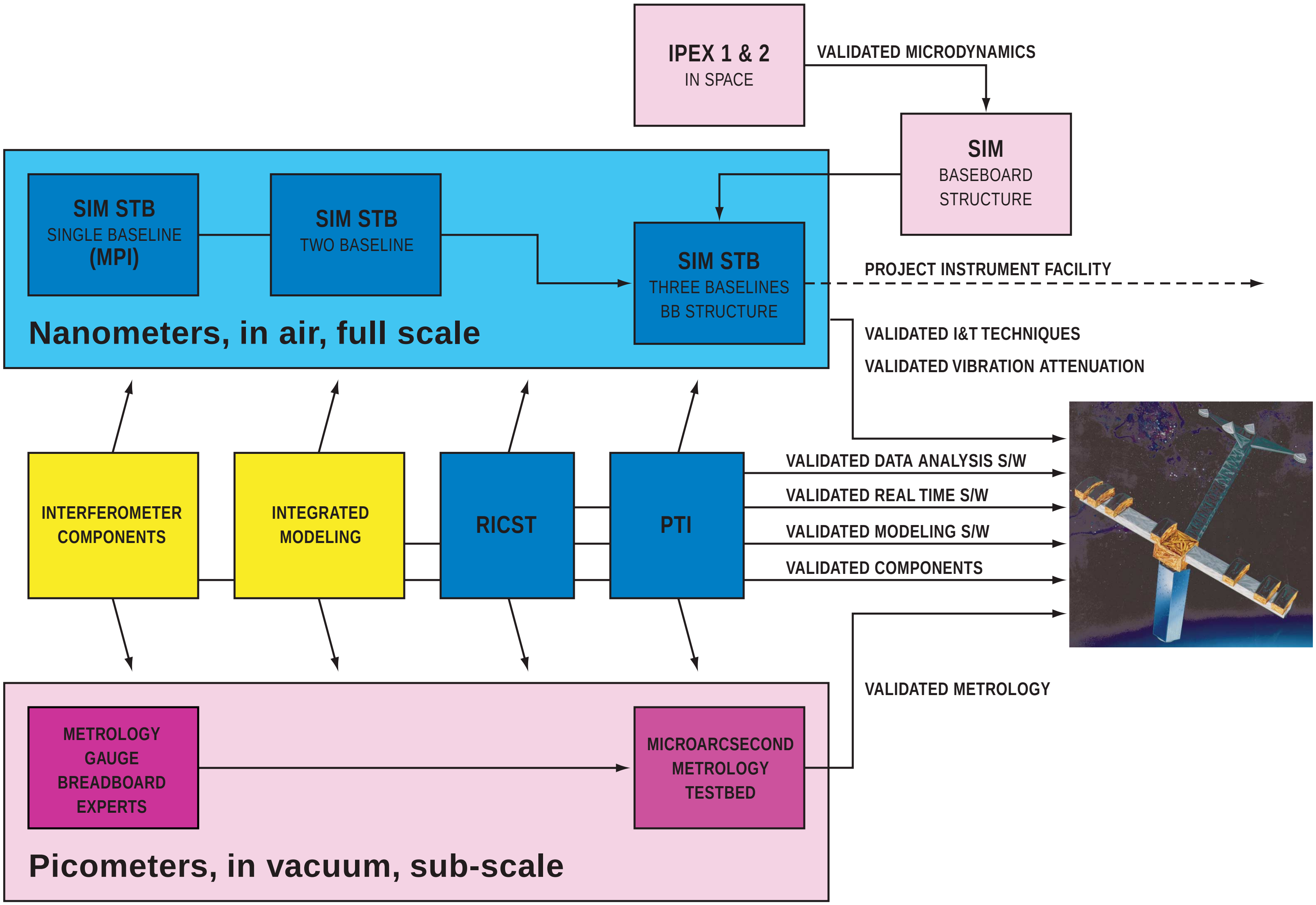


Figure 2-3. SIM Technology Development Flow

SIM STB

The SIM STB is actually an evolutionary series of three testbeds (see **Figure 2-4**).

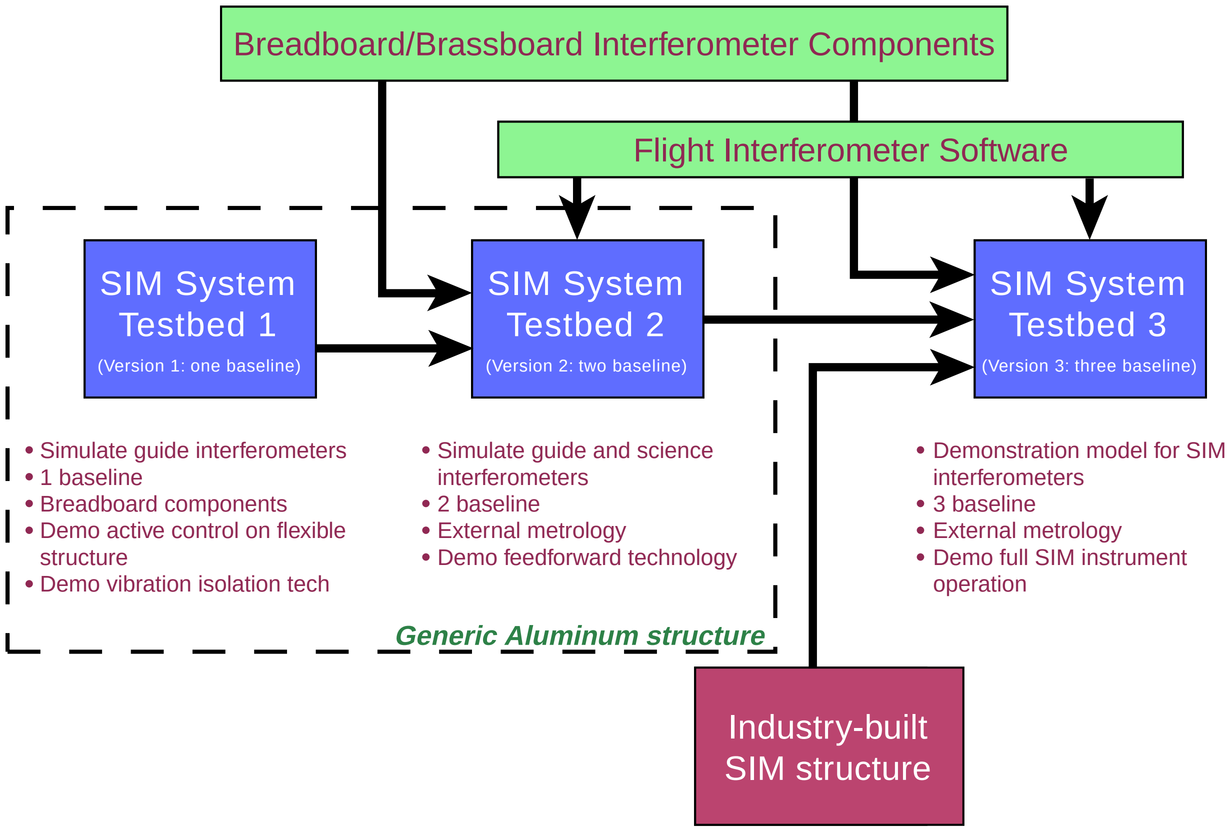


Figure 2-4. SIM STB Development Sequence

The first, STB-1, was built during the fiscal year 1991 through fiscal year 1994 timeframe. It is a full, single baseline interferometer built on a flexible structure out of breadboard hardware components (see **Figure 2-5**).

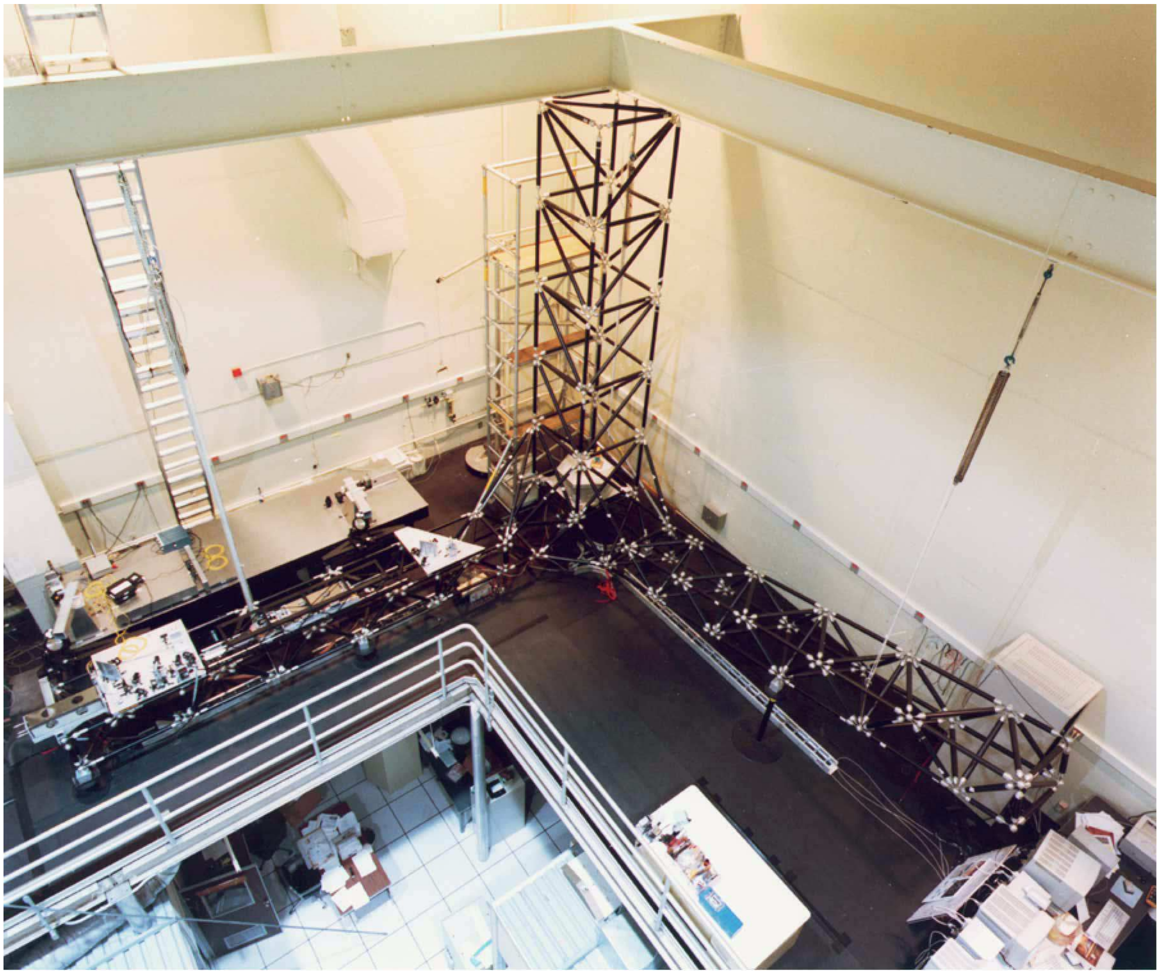
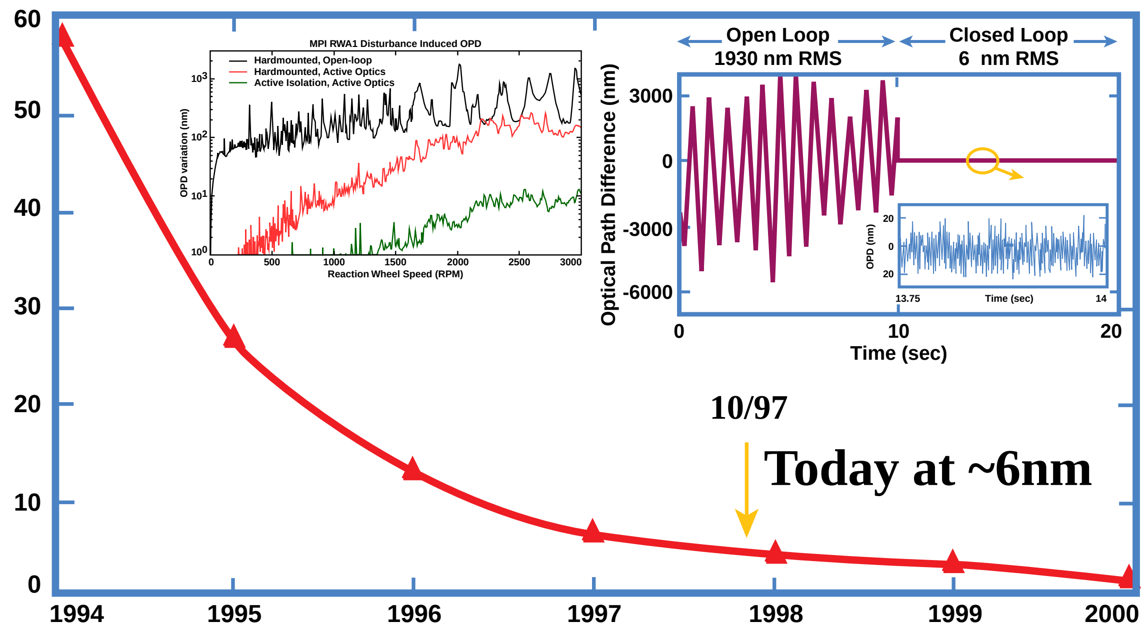
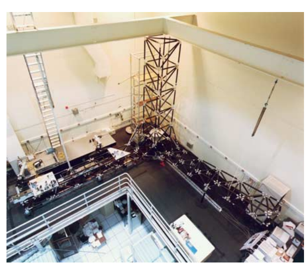


Figure 2-5. SIM STB-1, Bird's Eye View

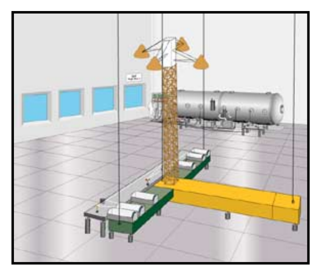
The structure is a 7m x 6.8m x 5.5m aluminum truss weighing 200 kg (with optics and control systems attached the weight is about 600 kg). Three active gravity off-load devices make up the structure's suspension system, providing about a factor of ten separation between the structure's "rigid body" and flexible body modes (the lowest of which is at about 6 Hz). The equipment complement includes a three-tier optical delay line with associated laser metrology, a pointing system complete with two gimballed siderostats, two fast steering mirrors, and coarse and fine angle tracking detectors, a six-axis isolation system , and all associated electronics and realtime computer control hardware necessary for closed loop system control and data acquisition. As shown in **Table 2-2**, the principal objectives of STB-1 are demonstrating vibration attenuation technologies and validating the IMOS modeling tool in the nanometer regime. STB-1 was completed during the summer of 1994 (when "first fringes" were acquired). Two metrics have been tracked over time to monitor testbed progress. These are: (a) pseudo-star fringe tracking stability in the presence of the laboratory ambient vibration environment and; (b) fringe stability versus emulated spacecraft reaction wheel disturbances, which are expected to be the dominant on-orbit disturbance source. As is seen in **Figure 2-6**, the current performance, as measured by each metric, is below 6 nm RMS. The goal is to achieve 1 nm by the end of the evolutionary STB program.

- *Requirements:*
  - *10 Nanometer for Astrometry*
  - *1 Nanometer for Nulling*





SIM System Testbed Version 1



SIM System Testbed Version 3

Figure 2-6. STB Nanometer Stabilization Progress Metric

Plans call for upgrading STB-1 by adding a second baseline to demonstrate feedforward from a guide interferometer (which views bright stars) to a science interferometer (which views dim stars that cannot be used for pointing and pathlength feedback control). Once the second baseline is operational, STB-1 will become STB-2. The level of hardware fidelity will increase slightly, as brassboard delay lines will replace the current breadboard system. STB-2 will also utilize RICST developed software, which is a departure from STB-1 that uses “homegrown” software with some heritage to the PTI software build.

STB-3 is essentially a new build from the ground up. The goal is to build as high fidelity a replica of the SIM instrument as funding and SIM design knowledge can afford. The latter is an important point: STB-3 will reach its critical design review years before SIM is even at the PDR level Hence, it is likely that the actual design of SIM will evolve somewhat from the design point when STB-3 is committed to hardware. The premise is that the experience gained in building and operating STB-3 at an early point in the SIM life cycle will be of sufficient value to far outweigh the small configurational changes that will certainly arise between the testbed and the actual flight instrument. Given that STB-3 will possess the same level of complexity as SIM, it represents the ultimate proving ground for RICST software. Having been wrung out on STB-3, this software should be ready for use on the flight system with only modest changes. STB-3 will also serve as the principal training ground for the SIM instrument development team. The intention is that the STB-3 team will be the same as the flight team, including industry participation. Hence the integration and test of STB-3 will be a dress rehearsal for the integration and test of SIM. Two other primary uses of STB-3 are also envisioned: as a staging and early test area for SIM flight hardware on its way to instrument integration and test; for flight instrument trouble shooting during mission operations. Hence, STB-3 is envisioned to play a central role in SIM instrument development throughout the life cycle of the project.

MAM Testbed

The MAM Testbed will demonstrate that picometer metrology components can be configured with a stellar interferometer, per the approach of the SIM instrument, to enable the measurement of point source (viz, pseudo-star) position to the microarcsecond level. This will be done at sub-scale in a 3m x 13m vacuum chamber. The MAM Testbed uses a 1.8 m baseline interferometer to observe an artificial star. The positions of the star and interferometer are monitored by an external metrology system that allows for calibration of the star position measured by the interferometer. The interferometer layout is shown in **Figure 2-7**.

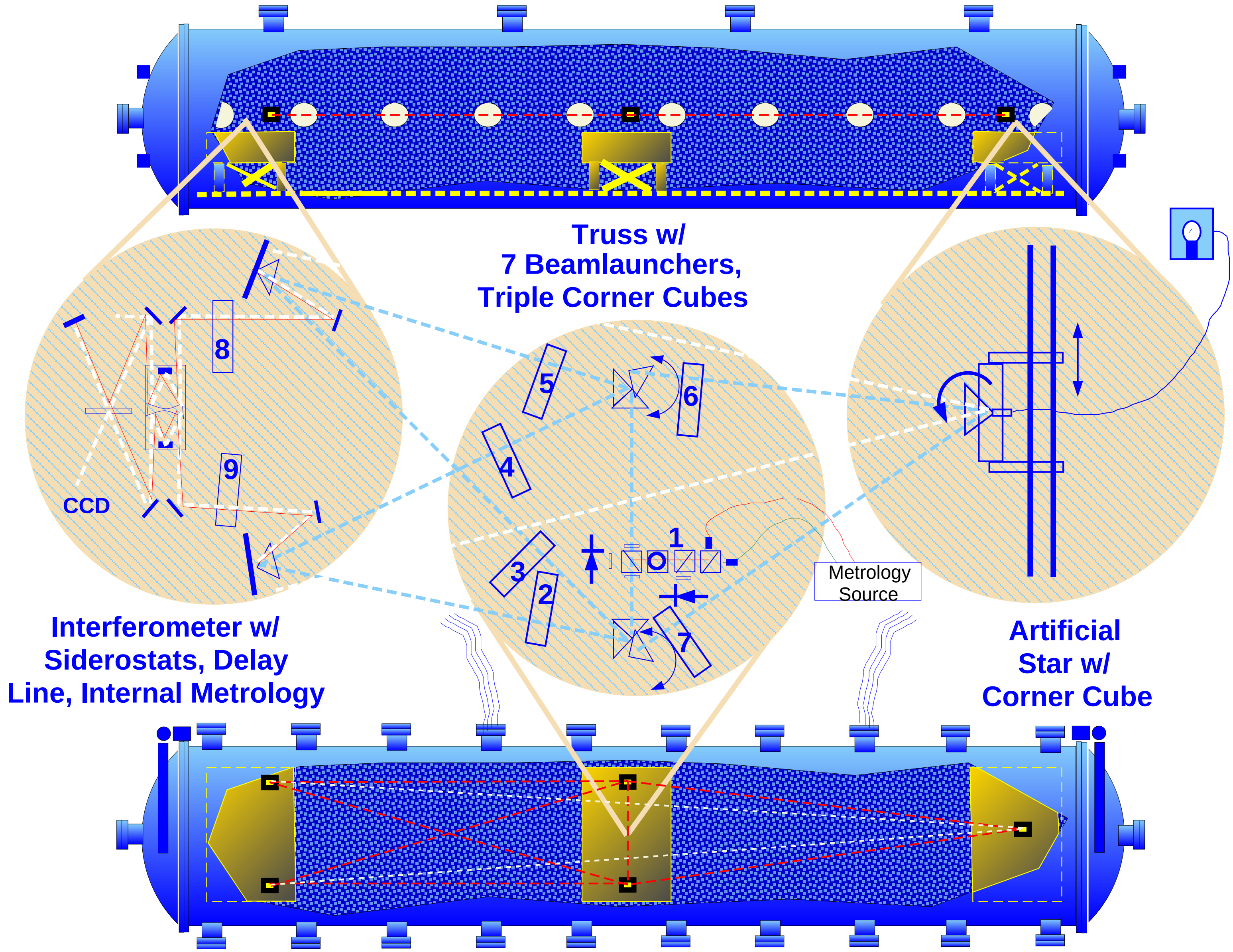


Figure 2-7. MAM Testbed Configuration

The interferometer includes siderostats for wide-angle acquisition, fast steering mirrors for fine guiding, a delay line for optical path control, and a beam combiner with both imaging and single-pixel detectors. The metrology system consists of nine beam launchers—two that monitor the star, two that monitor each siderostat, one that monitors the external metrology "truss," and two internal launchers that monitor the optical path length through the interferometer. In this way, the metrology system is a 2-D version of the 3-D system proposed for SIM. The interferometer includes all of the functionality of SIM (except for switching mirrors), in a reduced scale and reduced dimensionality experiment. The MAM optics, metrology system, and artificial star are placed in a vibration-isolated, thermally stabilized, vacuum chamber. This eliminates index of refraction fluctuations in air and allows the experiment to achieve its goal of 50 pm optical path measurement accuracy.

Initial MAM operation is planned for late in fiscal 1998 with a single-baseline narrow-angle experiment. The artificial star will be moved over a 20 arcsecond (1 mm) range and its position will be monitored by both the white-light interferometer and the external metrology system. The experiment will attempt to show that it is possible to measure the position of the star to within a few micro-arcseconds. The next stage of experimentation will be to increase the field-of-view (stellar motion), eventually reaching 1 degree. The controlled environment will be perturbed by adding heaters and vibration transducers to key optical components. In this way one can study the interaction of dynamic effects on the calibration and operation of the interferometer.

The MAM Testbed is the culmination of several years of sub-nanometer metrology work. **Figure 2-8** shows the progression from a stabilized laser through a one dimensional laser gauge through the currently active three dimensional metrology testing and on to the MAM Testbed.

PTI

The 110-meter baseline PTI (see **Figure 2-9**), in operation since July of 1995, was built primarily as a precursor and technology demonstrator for more advanced ground based interferometers like the planned Keck Interferometer.

However, it has also played and will continue to play a significant role in the development of technology for space based interferometers. PTI pioneered the development of realtime software for interferometer control. Its realtime software "shell" was later adopted by STB-1 and is serving as the basis for the RICST software development approach. As a demonstration of the type of autonomy required for the operation of space systems, PTI has been operated remotely from JPL, more than 100 miles away.

In the future, PTI will serve as a development platform for interferometer science data processing software. Utilizing its unique dual star feed mode, PTI will be able to make narrow angle astrometric measurements at accuracies under 100 microarcseconds, unprecedented for a ground based system. Such measurements will be a reasonable facsimile of the 1 microarcsencond narrow angle astrometry that SIM will perform. Hence, the data processing software developed for the PTI astrometry will become the core of the SIM narrow angle astrometry science software.

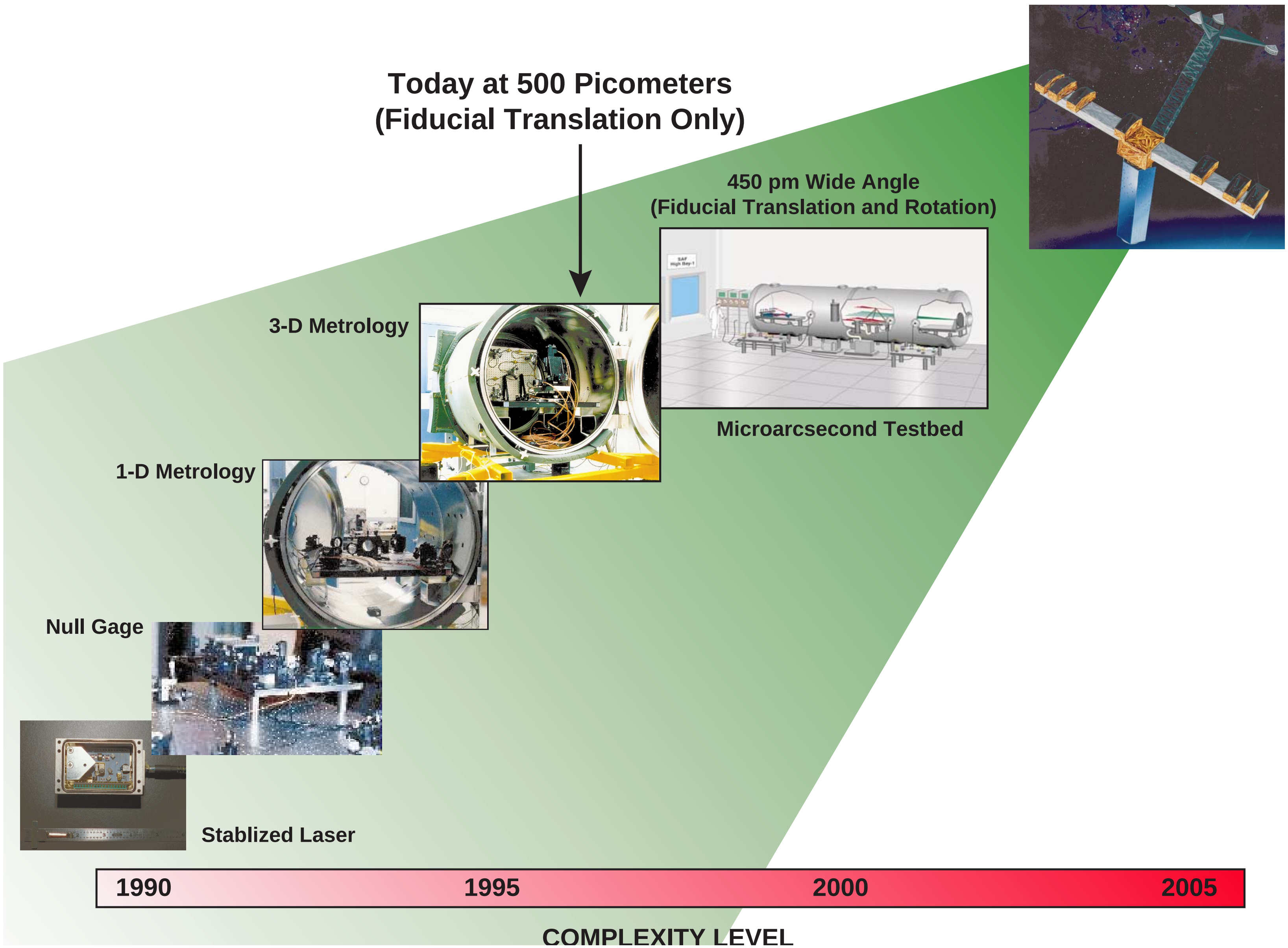


Figure 2-8. Sub-nanometer Metrology Progress Metric

Figure 2-9. The PTI

RICST

As described in Section 2.2.2, RICST has the objective of developing prototype realtime interferometer control software. This software will serve to operate the MAM as well as the STB-2 and STB-3 testbeds and, with minor rework, it is planned that this prototype software will become the flight software that operates the SIM interferometer instrument. RICST will incorporate various pieces of interferometer component hardware into its development environment since the effective development of realtime control code is greatly facilitated by having the actual hardware to be controlled present for interface checkout and feedback testing. The full complement of RICST resident component hardware will allow the software to operate a single baseline interferometer sitting in the lab on a set of optical benches.

Building upon the PTI and STB-1 software developments, which were both exploratory efforts requiring a significant degree of bottom-up engineering, RICST will pursue a more formal top-down pass through the development of the core interferometer realtime embedded system implementatiuon. Development will occur via a series of incremental deliveries of software modules. Planned increments include: delay line initial operation, full function delay line, phasing system hardware, white light fringe tracking, MAM narrow angle operation, STB-2 single baseline operation, STB-2 two baseline operation, MAM wide angle operation, STB-3 initial full function, STB-3 software upgrades. **Figure 2-10** gives a picture of where the RICST development effort currently stands from the module development perspective.

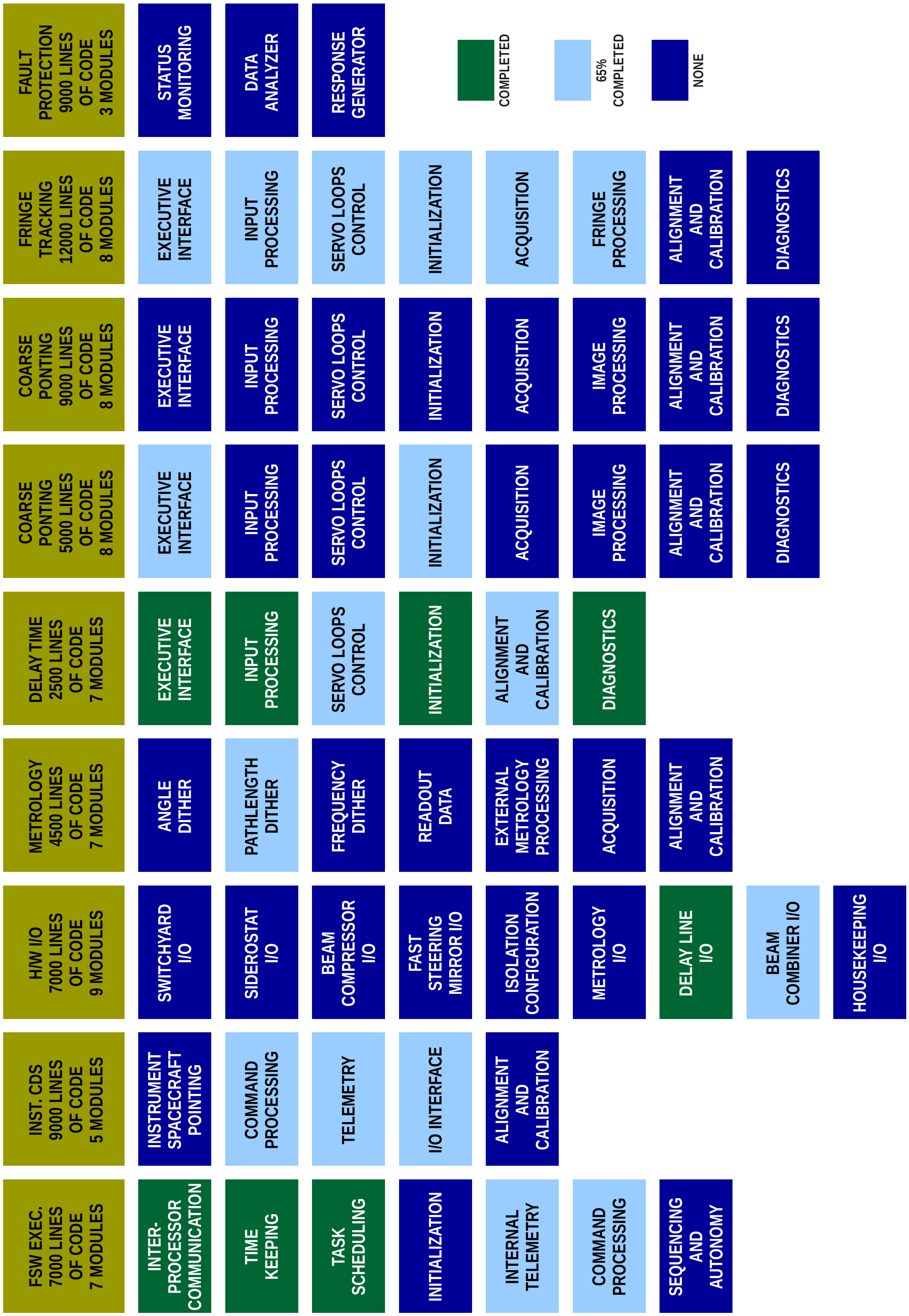


Figure 2-10. Status of RICST Software Development (as of 12/97)

In addition to MAM, STB, and SIM, RICST developed software is expected to play a role in operating the Keck Interferometer, DS-3, and the Georgia State University (GSU) Mount Wilson Interferometer.

2.2.4.2 Flight Experiments

The technology for deployable structures is considered to be relatively mature from the standpoint of scale (> 50 meter in length), initial deployment accuracy (millimeters), and long time scale stability over thermal loads (millimeters). On the other hand, the on-orbit short time scale stability (viz., above 1 Hz) of these systems in the nanometer regime is completely unknown. The concern is that deployable structures are dominated by hinges, latches, and joints all of which have the potential to exhibit stick-slip nonlinearities which are particularly susceptible to “creaking” due to time varying thermal conditions. Such creaking would be likely to have broad frequency content given its impulsive nature and hence, even if it occurs on the micron scale, could be quite problematic for an interferometer whose actively controlled optics might not have sufficient bandwidth to track it out.

Ground based experimental investigations into the microdynamic behavior of deployable structures is very difficult. In particular, testing in 1-g suffers from the inability to perfectly remove gravity induced internal loads from the test specimen in order to emulate on-orbit conditions. These gravity induced “preloads” could well act to completely hide the suspected stick-slip phenomena which would be unleashed only in space. This is the motivation for conducting space experimentation in order to understand the microdynamics of deployable structures.

IPEX-1 was the first step toward filling the microdynamics information gap. Hosted on DARA’s (German Space Agency) Astronomical Shuttle Pallet Satellite (Astro-SPAS) platform, which flew a shuttle sortie mission on Space Transport System-80 (STS-80) in December 1996, IPEX-1 gathered twelve channels of micro-g acceleration data using Sunstrand QA-2000 accelerometers sampled at 744 Hz. During quiet periods when thrusters were not operating, accelerations of the order of 100 micro-g’s were measured. This data tells us two important facts: (i) the microdynamics of built up monolithic structures like Astro-SPAS appear compatible with interferometer mission requirements; (ii) the Astro-SPAS is a quiet enough platform to host future Origins flight experiments. The first of these, IPEX-2, was flown in August 1997, a scant eight months after IPEX-1. IPEX-2 (see **Figure 2-11**) consisted of an instrumented portion of a representative deployable structure, a so-called ADAM-Mast built by ABLE Engineering of Goleta, California. IPEX-2 mission operations went perfectly. Over 60 channels of accelerometer, load cell, and temperature data were taken during various orbital thermal conditions including Sun-shade transitions and long duration hot and cold soaks. This data will be analyzed over the course of fiscal 1998. Taken together with ground test data the intent is to develop empirically validated analytical models capable of predicting the conditions leading to and the vibrations emanating from thermal creaks. This work will be carried out by JPL in conjuction with NASA Langley Research Center (LaRC) and will involve university participation from MIT and the University of Colorado.

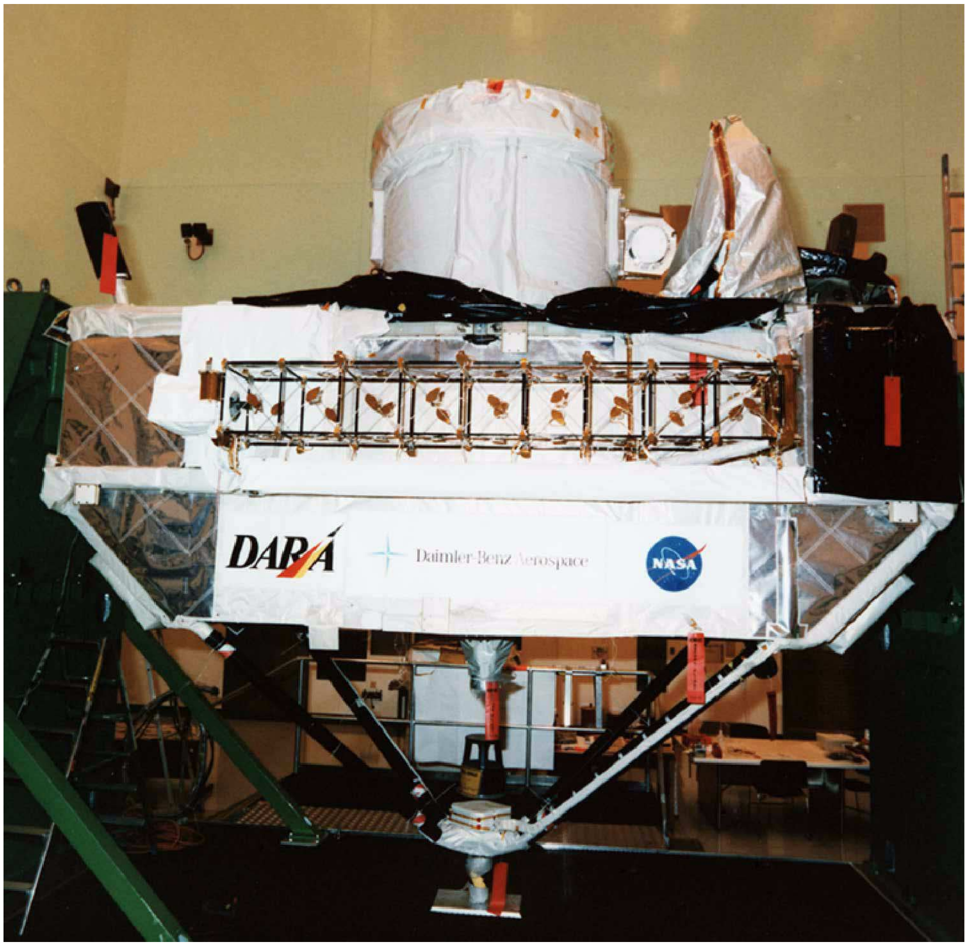


Figure 2-11. IPEX-2 Integrated to Crista-SPAS and Ready for Launch

3. TECHNOLOGY DEVELOPMENT IMPLEMENTATION PLAN

3.1 Programmatic Assumptions

3.1.1 Industry and University Involvement

The small business community will be engaged in the development of interferometry technology to a great extent via NASA's SBIR Program. The NASA SBIR Program is responsible for the distribution of over $100M per year of NASA funds to small businesses for the development of innovative ideas which have high potential for contributing to NASA's mission and developing into commercially viable products. SBIR awards are made in two phases: Phase 1 awards are for a duration of 6 months at a dollar value of approximately $70K and cover the development of a design concept; Phase 2 awards are typically for a duration of 18 to 24 months, at a dollar value up to $700K, and cover product development through proof-of-concept (at which point it is ready to be picked up by a NASA mission or marketed commercially).

The SBIR Program is organized into a set of 28 "Topics" which are in turn subdivided into a total of 118 "Subtopics." Topic and Subtopic managers have wide latitude as to the ranking and selection of proposals within their Topic and Subtopic areas. As of the fiscal year 1996 SBIR solicitation, a Topic was established in Space Based Optical Interferometers consisting of three Subtopics: Metrology and Starlight Detection Systems; Active Optics; and Ultra-Quiet Precision Structures. Bob Laskin is the Topic manager and the Subtopic managers are, respectively, Jeff Yu, Gary Blackwood, and Marie Levine-West. As of fiscal year 1997, the Interferometry Topic had 13 active Phase 1 efforts and three active Phase 2 efforts, representing close to $2M of SBIR Program support.

The intent of the Interferometry Topic is to use the SBIR Program to identify potential interferometry solutions beyond those supported within the baseline program under Office of Space Science funding. Utilizing the SBIR Program in this way allows the investigation of higher risk, higher payoff approaches without injecting unacceptable risk into the development of technology for SIM. Another benefit is an expansion of the potential vendor base for development of components and software for the SIM project, with an expected downward pressure on costs to SIM due to greater competition within the industrial base. The approach to incorporating SBIR products into the technology program relies on the inclusion of components and software that result from Phase 2 efforts into our testbeds and environmental tests, thereby "qualifying" them as "interferometer mission ready." Although it is not anticipated that a large percentage of efforts that start as Phase 1 SBIRs will result in mission ready products, those that do should greatly enhance the ability to execute SIM on a cost effective basis. It is important to note that involvement in the SBIR Program does not preclude a small company from bidding in a competitive manner on any of the subsystem and component hardware Request for Proposals (RFP) that are anticipated to be put forth (refer to Section 2.2.1).

Involvement of the large aerospace companies (the so-called “primes”) in the technology program will take place in conjunction with the SIM Project. As described in Section 2.2.4, STB-3 will be the main vehicle for involving large industry. The goal is to implement the STB-3 design, build, and test in exactly the same manner, both technically and programmatically, as the SIM flight instrument. Large aerospace companies will be involved accordingly.

Universities will be involved in the development of interferometry technology largely via contracts with the appropriate entities within the JPL work breakdown structure. Examples are currently active contracts with MIT and University of Colorado to perform microdynamics research, and another contract with MIT to support testbed modeling. There is one activity where JPL is serving as the contractor for a university: the RICST team is supporting GSU for the development of a delay line control system for a ground based interferometer that GSU will operate on Mount Wilson in Southern California beginning about 2000.

3.1.2 Partnerships—Other NASA Centers, Agencies, and International

As of this writing, no other NASA centers, U.S. Government Agencies, foreign agencies or foreign companies will play a principal role in the development of the interferometry technology for SIM. The role of principal will be played by JPL in collaboration with U.S. industry.

Nevertheless, the technology program will certainly seek out synergistic arrangements with other entities whenever these arrangements promise to have a positive impact on the development of SIM technology. An example of such an arrangement is the collaboration with the Air Force Phillips Lab (AF/PL) to develop the Vibration Isolation Suppression and Steering (VISS) flight experiment to be flown as part of the Air Force’s Space Technology Research Vehicle-2 (STRV-2) Program. VISS will demonstrate active vibration isolation in space, a technology critically important to SIM. The development paired NASA/JPL, responsible for the flight control law software, with AF/PL, responsible for contracting for development of VISS hardware and overall system integration and test. VISS is slated to fly in the summer of 1998, with ITP playing a role in mission operations.

Potential future collaborations could emerge with GSFC’s NGST Program. Technologies, such as integrated modeling, vibration isolation, active optical control and, perhaps, laser metrology, would be candidates for joint ventures with NGST. Collaborations will be pursued in cases where cost reduction for both SIM and NGST seems likely to result. In addition, NGST is planning to flight demonstrate a large, inflatable sunshield in the fiscal year 2000 timeframe. Should the SIM design adopt a sunshield, this flight experiment would certainly become an important area of technical cooperation.

There is also the potential for collaboration between NASA/JPL and elements of the Department of Defense (DoD) and/or DoD contractors in areas of common technological interest.

In general, the prospects for synergistic collaborations with other government entities will be monitored via periodic visits and technical interchanges with these entities. Keeping abreast of the state-of-the-art in interferometry technology through regular attendance at appropriate technical conferences and meetings, a close reading of the technical literature, and participation in national advisory groups is also critical.

3.1.3 Resource Assumptions

The resources necessary to implement this technology plan are described at length in Section 3.2. These resources, broadly speaking, fall into three categories: money, people, and facilities. Funding will be provided by the Office of Space Science; in-house personnel by JPL’s Engineering and Science Directorate. The assumed profile for these two critical resources are:

	FY’97	FY’98	FY’99	FY’00
Funding (M$)	9.0	21.0	16.0	13.5
Workyears (FTEs)	37.4	71.6	55.5	49.6

3.2 *Summary Level Implementation Plan*

This Section contains a high-level implementation plan for ITP implementation. A detailed TIP will be written for individual WBS elements in response to the outline and requirements set forth in this plan.

3.2.1 *Implementation Flow*

ITP consists of two distinct areas of development. First, a set of generic technologies applicable to a number of missions and projects and second, technologies related solely to the SIM Project. As shown in the Flow Chart, **Figure 3-1**, the SIM Project inherits integrated modeling tools for complex optical systems and validated microdynamics models from the generic technology efforts. The SIM technology development effort will consist of:

(a) System engineering efforts to develop system and subsystem performance requirements, including interferometer design methodology, validation of modeling tools, and requirement test and traceability matrices for verification and validation.

(b) Development of critical control algorithms and hardware and software components to mitigate project implementation risk and populate testbeds as required.

(c) Development of testbeds to conduct interferometer performance tests for validation of components, modeling tools, and integration and test methodologies prior to Project phase C/D start.

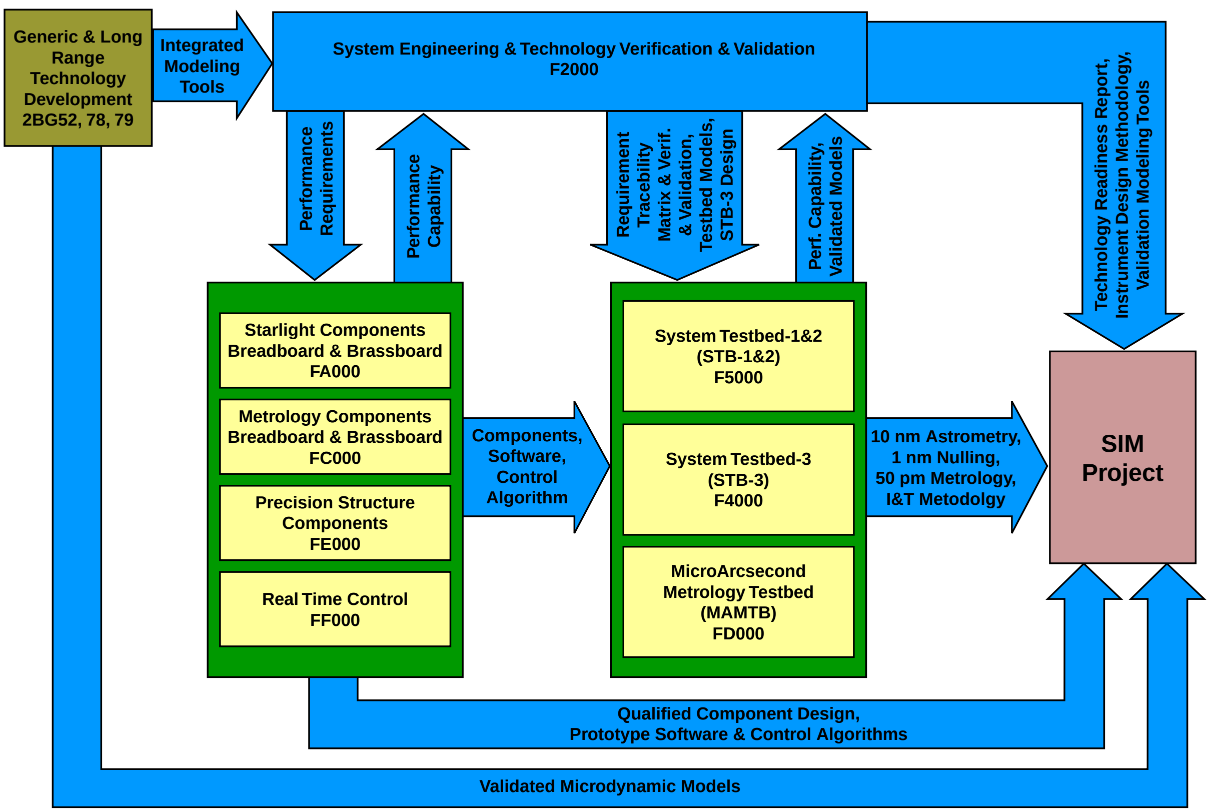


Figure 3-1. SIM Technology Implementation Flow

3.2.2 WBS

Table 3-1 provides the ITP WBS, which was developed to be traceable to and aligned with the SIM Project. Each SIM instrument functional area (Instrument System Engineering, Starlight, Metrology, Precision Structure, Real Time Control, and I&T) has a counterpart within ITP WBS. Separate top-level WBS elements are assigned to MAM and STB-1&2 as major standalone testbeds. The implementation of STB-3 is spread across many WBS elements to simulate the implementation of the SIM flight instrument. WBS element 234-F4000 is for the STB-3 integration and test activity only. Finally note that, the generic technologies (such as Integrated Modeling Tool Development, Long Range Planning, etc.) are bookkept under the ITP Management WBS element. The flow chart in **Figure 3-1** also shows how the WBS elements interrelate to one another and the SIM Project.

Table 3-1. SIM Technology Work Breakdown Structure

- 234-2BGXX: ITP Management
  - 2BG51: ITP Management
  - 2BG52: IMOS Tool Development
  - 2BG54: VISS
  - 2BG78: Microdynamics
  - 2BG79: Long Range Planning
  - 2BG84: ITP Carry-Forward
  - 2BG85: ITP Strategic Reserve

- 234-F000: Instrument System Management
  - F1000: Instrument System Management
  - F1100: SIM TAC Administration

- 234-F2000:System Engineering and Technology Validation
  - F2500: ITP System Engineering and Technology V&V

- 234-FA000: Starlight Components (STLT)
  - FA100: Starlight Management
  - FA200: Mono Collector Unit
  - FA300: Switchyard Unit
  - FA400: Active Delay Line Unit
  - FA500: Passive Delay Line Unit
  - FA600: Astrometric Beam Combiner Unit)

- 234-FC000: Metrology Components (METR)
  - FC100: Metrology Management
  - FC300: Dual Freq Laser Source Units
  - FC400: Reference Fiducials Unit
  - FC500: Fiber Splitters Unit
  - FC600: Metrology Beam Launchers Unit

- 234-FD000: Microarsecond Metrology Testbed (MAM)
  - FD100: MAM Management
  - FD200: Opto-Mechanical
  - FD300: MAM Electronics
  - FD400: MAM Opto-Mechanical WF
  - FD500: MAM Electronics WF

- 234-FE000: Precision Structure Components
  - FE100: ITP PSS Management

- 234-FF000: Real time Interferometer Control S/W Testbed
  - FF100: RICST Subsystem Management & S/S engineering
  - FF200: Control Algorithm Development
  - FF300: Real time Software
  - FF400: RICST Electronics
  - FF500: RICST I&T

- F4000: SIM System Testbed 3 - STB-3 (I&T)
- F4100: STB-3 Management
- F4200: ITP II&T Palomar Support

- F5000: SIM System Testbed 1&2 (STB2) I&T
- F5100: STB-1&2 Management

At least once each year, or as directed by the Program Office, each Project Element Manager (PEM) responsible for a WBS element shall:

- Estimate the element's resource needs to complete the work
- Negotiate a resource budget with the WBS element's funding authority

Resource transfers may be traded among different WBS elements. Individual WBS elements with unused budgetary allocation at the end of the fiscal year, based on concurrence of the ITP Program Manager, may carry the allocation forward into the next fiscal year.

3.2.3 WBS Dictionary

ITP Management: Development of plans, requirements and negotiation of resources with project and line organizations for interferometry technology development. Also, monitor and control of resources to insure program implementation in accordance with planned resources.

Integrated Modeling Tool Development: Development, integration, and validation of appropriate software modeling tools (IMOS) to facilitate the design and performance prediction of complex systems containing mechanical, electrical and optical subsystems.

VISS: Development of flight control system software for the Vibration Isolation Suppression and Steering system to be flown on board the Ballistic Missile Defense Organization (BMDO) STRV-2 experiment.

Microdynamics: Characterization of structural microdynamic behavior of deployable structure in a microgravity environment.

Long Range Planning: Development of new technology plans and roadmaps beyond SIM interferometry project in response to JPL and NASA management.

Palomar Testbed Support: Upgrades and maintenance of the 110-meter Interferometer at Palomar mountain.

ITP Carry Forward: Funds set aside for carry forward to next fiscal year for covering six weeks of essential obligation, prior to availability of sponsor funds.

ITP Strategic Reserve: Funds for unplanned or unpredictable obligations or scope change.

Instrument System Management: Development of plans and requirements for WBS elements related to interferometer instrument system technology. Control and monitoring of resources and progress with respect to planned implementation.

System Engineering and Technical Validation and Verification: Design and development of technical requirements for STB-3 and interferometer testbed validation and verification methodology. Requirement flow-down to subsystem level. Coordinate testbed modeling activity.

Starlight Components: Development of breadboard and brassboard opto-mechanical components which collect starlight and forms white light fringe consisting of Mono Collector Unit, Switch Yard Mirrors, Active Optical Delay Line, Passive Optical Delay

Line and Astrometric Beam Combiner housing the fringe detectors. Starlight component fabrication for STB-2 and STB-3.

Metrology Components: Development of breadboard and brassboard opto-electronics components to measure the position of Starlight components of the interferometer instrument to sub nanometer accuracy. Metrology Components consist of Dual Frequency Laser Source Unit, Reference Fiducial Unit, Fiber Optic Splitters Unit and Metrology Beam Launcher Unit. Metrology component fabrication for MAM and STB-3.

MAM Testbed (MAMTB): Development of the scale model of an interferometer instrument to be tested in a vacuum environment for validation and verification of the required Narrow Angle and Wide Angle metrology to microarcsecond accuracy. MAM is responsible for the design, fabrication and procurement of its own starlight components.

Precision Structure Components: Development of required components to provide an ultra-stable and predictable platform for starlight and metrology components of the interferometer instrument; STB-3 structural component (except the structure) fabrication.

Real-time Control Software Testbed: Development of the electronic hardware, control algorithms, computer and software for the real time control and operation of STB-2, STB-3 and MAM. Development of prototype flight software for the SIM interferometer instrument.

SIM STB-3 Interferometer I&T: Development of the required facility and Integration and Test of the full scale multi-baseline interferometer. Also conduct experiments for required performance validation and verification.

SIM STB-1&2 Interferometer I&T: Conduct experiments on the 4-meter single baseline interferometer STB-1 (formerly MPI) to achieve optimum predicted path length control. Upgrade STB-1 to a dual 4-meter baseline interferometer, STB-2, and conduct experiments for required performance, validation, and verification.

3.2.4 Requirements

The System Engineering and Technology Validation and Verification (V&V) WBS element will develop detail system and subsystem requirements traceable to SIM technology requirement. This WBS element shall also develop methodologies for validation and verification and tracking of the system and subsystem performance with respect to the requirements. The TIP for this WBS element shall outline the requirements and V&V methodologies.

3.2.5 Master Test Plan

A verification and test program will be outlined for each WBS element in their respective TIP to verify compliance with requirements, as well as to demonstrate performance margins where applicable. A Requirement and Test Traceability Matrix shall be generated to facilitate the verification process.

The verification program will be conducted in a top-down fashion from external interface requirements down, and in a bottom-up fashion from component level up. Performance verification implementation will include modeling and analysis.

3.2.6 Top Level Schedule

Figure 3-2 shows the Top Level ITP Schedule. The ITP schedule incorporates a multi-phase program, consistent with various phases of SIM Project development. The preliminary phase starts with development of breadboards and brassboards of critical interferometer components and ends with fully functional Interferometry Testbeds in time for start of phase C/D of the SIM Project.

The component qualification program will develop a total of 19 breadboards and 23 brassboards of critical hardware components by the end of fiscal year 2000. The brassboard components will be capable of full SIM functional performance and will be environmentally tested to levels specified in the appropriate TIPs, while the breadboards will be developed for functionality only.

The necessary electronic hardware and interferometry real-time control software will be developed and tested incrementally, with completed version 1.0 available by the fourth quarter of fiscal year 1999 for the STB-3 Testbed. Subsequent upgrade versions 1.1 and 1.2 release will be used by STB-3 in fiscal year 2000. Initial incremental deliveries will be made to MAM and STB-2 starting in fiscal year 1998.

The MAM Testbed design of a scaled baseline interferometer in a vacuum tank started in fiscal year 1997. The Narrow Angle performance testing will be completed by the end of March 1999 and the Wide Angle performance testing by August 1999, 18 months before SIM PDR.

The 4-meter single baseline interferometer STB-1, formerly known as the MPI Testbed, will complete performance testing and model validation by the end of fiscal year 1998. This testbed will be upgraded to a dual baseline interferometer called STB-2 in a phased fashion and complete its performance test by the end of fiscal year 1999. The STB-1 upgrade to STB-2 will be done in such a way as to maintain one operational baseline prior to integration of both baselines in fiscal year 1999. The design of a SIM-like 10-meter three baselines interferometer testbed called STB-3 will start in fiscal year 1998 and complete its performance test and model validation two month prior to SIM project NAR/PDR. The two months will be used as schedule contingency.

ITP has been developing, and will continue to improve, the IMOS tool for modeling and performance prediction of complex optical systems. IMOS will be used by SIM and other projects as a design tool and for in-orbit performance prediction. IMOS versions 3.0 and 4.0 will be released by January and August of fiscal year 1998, respectively. The Versions 5.0 and 6.0 will be released by August 1999 and 2000, respectively. The IMOS tool will also be used to model MAMTB and the STBs where its predictive capability will be test validated.

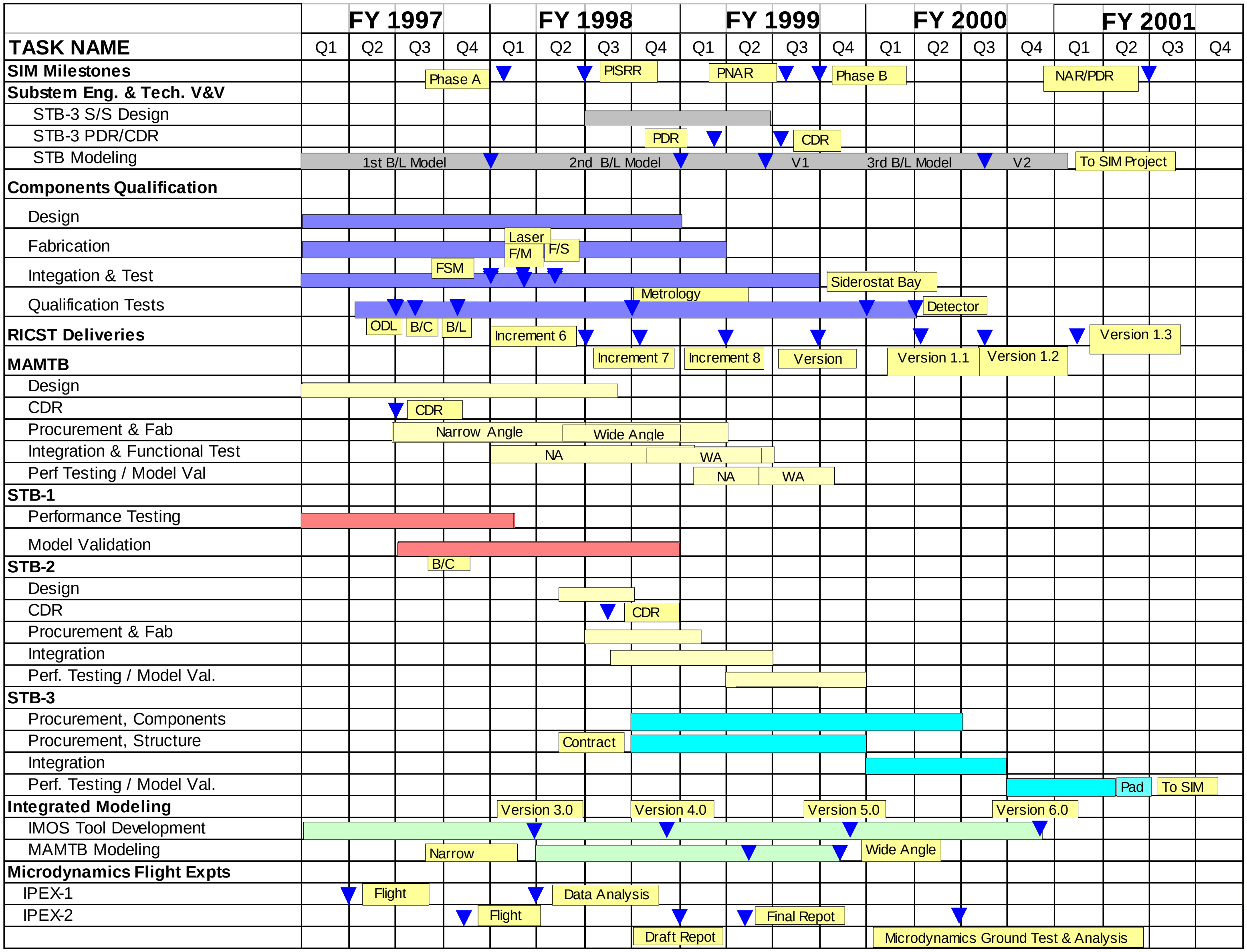


Figure 3-2. SIM Technology Implementation Schedule

IPEXs 1&2 have been launched aboard the Shuttle as part of the German Astro-SPAS free flyer spacecraft to study the Microdynamics behavior of precision structures in the micro-gravity environment of space. IPEX-1 was launched in December of 1996 and IPEX-2 was launched in August of 1997. The data analysis effort will continue through fiscal year 1999 with comparison to ground test data. The IPEX-1 data analysis Report will be released by January 1998 and the IPEX-2 Report by February 1999, with a Draft release by September 1998. The Microdynamics Ground Test Report will be released by October 1999.

3.2.7 Major Deliverables and Milestones

Table 3-2 shows a list of major ITP Deliverables and Milestones. The ITP Deliverables and Milestones are consistent with the SIM Project requirement need dates.

Table 3-2. SIM Technology Major Deliverables and Milestones

Title	Date	Performance Metric	Comments
SIM Technology Plan	January 15, 1997	N/A	
Brassboard Components			
Optical Delay Line	March 15, 1997	5 nm control at Tracking	Completed
Astrometric Beam Combiner	April 15, 1997	0.85 Static Fringe Visibility	Completed
Beam Launcher	July 15, 1997	5nm Self interference	Completed
Metrology Source	February 19, 1998	1.3 kHz Freq. Stability	Deliver to MAMTB
Siderostat	September 15, 1999	±0.02 arcsec Accuracy	Deliver to STB-3
Detectors	December 15, 1999	3 e rms Read Noise @50kps	Deliver to STB-3
System Eng. and Tech. Verif. & Valid.			
STB-1 Model	September 15, 1997	1.5 rms Uncertainty Factor	Completed
STB-2 Model	December 15, 1998	1.5 rms Uncertainty Factor	Deliver to STB-2
STB-3 CDR	April 5, 1999	N/A	Present to SIM/TAC
STB-3 Model version 1.0	May 10, 1999	2.5rms Uncertainty Factor	Deliver to STB-3
STB-3 Model version 2.0	June 15, 2000	1.5rms Uncertainty Factor	Deliver to STB-3
Real-Time Control			
Increment 5 S/W	March 15, 1998	Limited Single B/L Operation	Deliver to MAMTB
Increment 6 S/W	July 15, 1998	Full Single B/L Operation	Deliver to STB-2
Increment 7 S/W	October 15, 1998	Dual B/L Operation	Deliver to STB-2
Increment 8 S/W	December 15, 1998	Wide Angle Operation	Deliver to MAMTB
Control Electronics H/W	October 1, 1999	Complete M&C Hardware	Deliver to STB-3
Version 1.0 S/W	October 1, 1999	First S/W release	Deliver to STB-3
Version 1.1 S/W	January 1, 2000	Upgrade to Ver. 1.0	Deliver to STB-3
Version 1.2 S/W	May 1, 2000	Full Control and Auto Align	Deliver to STB-3
Version 1.3 S/W	February 1, 2001	Upgrade to Ver. 1.2	Deliver to STB-3
Control Algorithms Version 1.0	July 1, 1999	N/A	Deliver to RTC
Control Algorithms Version 1.1	November 1, 1999	N/A	Deliver to RTC
Control Algorithms Version 1.2	March 1, 2000	N/A	Deliver to RTC
Control Algorithms Version 1.3	December 1, 2000	N/A	Deliver to RTC

Table 3-2. SIM Technology Major Deliverables and Milestones (cont'd)

Title	Date	Performance Metric	Comments
MAMTB			
CDR	March 15,1997	N/A	Completed
NA Performance test	March 12, 1999	20 µ arcsec over 20 arcsec	Report to SIM
WA Performance test	July 27, 1999	20 µ arcsec over 1.0 deg	Report to SIM
STB-1 Performance Report	September 15, 1998	4 nm rms Pathlength Control	Report to SIM
STB-2			
CDR	May 6, 1998	N/A	Present to SIM/TAC
Performance Report	September 20, 1999	30 nm rms Stabilization	Report to SIM
STB-3			
Structure on contract	July 1, 1998	N/A	
Performance Report, 10 nm	October 16, 2000	10 nm rms Stabilization	Report to SIM PDR/NAR
Performance Report, 1 nm	January 15, 2001	1 nm rms Nulling	Report to SIM PDR/NAR
Microdynamics flight experiment			
IPEX-1 Report	October 15, 1997	N/A	Launched December 1996
IPEX-2 Report	September 15, 1998	N/A	Launched August 1997
Ground test & analysis	September 15, 1999	N/A	Report to SIM
IMOS			
Version 3.0	January 15, 1998	N/A	Deliver to users
Version 4.0	August 2, 1998	N/A	Deliver to users
Version 5.0	August 2, 1999	N/A	Deliver to users
Version 6.0	August 2, 2000	N/A	Deliver to users

3.2.8 Budget and Workforce

The budget necessary for implementation of the technology plan will be provided by NASA Office of Space Science and the workforce will be provided by the JPL technical and support Divisions. **Tables 3-3** and **3-4** identify the allocated budget and workforce by WBS elements.

Table 3-3. SIM Technology Budget Plan

ITEMS	FY 96	FY 97	FY 98	FY 99	FY 00	TOTAL
Total HQ Funds	5,900K	9,000K	21,000K	16,000K	13,500K	**65,400K**
Carry In		260K	700K	2,550K	1,350K	
Carry Out	-260K	-700K	-2,550K	-1,350K	-600K	
Unencumbered Reserve			-314K	-150K		
CIT Tax	-54K	-88K	-185K	-144K	-122K	
RRA Per HQ			-38K			
Additional HQ Tax			-108K			
FY'98 Advance Funds Payback			-283K			
Available Funds Total	**5,586K**	**8,472K**	**18,222K**	**16,906K**	**14,129K**	**63,315K**
ITP Breakdown						
Management	540K	560K	248K	511K	456K	**2,315K**
Encumbered Reserve			730K	2,519K	1,423K	**4,672K**
Generic & Long Range Technology	915K	1,074K	1,337K	1,142K	1,270K	**5,738K**
SIM/ITP	4,131K	6,838K	13,807K	12,734K	10,980K	**48,490K**
Accellarated SIM Tech for DS-3			2,100K			**2,100K**
Dispersed Funds Total	**5,586K**	**8,472K**	**18,222K**	**16,906K**	**14,129K**	**63,315K**
SIM/ITP Breakdown						
Instrument System Management			442K	354K	355K	**1,151K**
System Eng. & Tech Validation			473K	700K	575K	**1,748K**
Starlight	1,662K	1,042K	3,716K	2,576K	2,197K	**11,193K**
PSS	439K	1,779K	479K	308K		**3,005K**
Metrology	870K	756K	1,630K	2,392K	1,900K	**7,548K**
Micro Arcsecond Metrology (MAM)		1,510K	2,620K	941K	587K	**5,658K**
RTC	472K	704K	2,337K	2,614K	2,398K	**8,525K**
STB-1 (MPI)	688K	864K	532K			**2,084K**
STB-2			1,305K	1,423K	82K	**2,810K**
STB-3			145K	1,299K	2,757K	**4,201K**
PTI		183K	128K	127K	129K	**567K**
Total	**4,131K**	**6,838K**	**13,807K**	**12,734K**	**10,980K**	**48,490K**
Generic & Long Range Plan Breakdown						
IMOS Tool Development	325K	251K	375K	445K	445K	**1,841K**
VISS	373K	273K	75K			**721K**
Microdynamics	217K	490K	637K	547K	547K	**2,438K**
Long Range Technology Development (TPF...)		60K	250K	150K	278K	**678K**
Total	**915K**	**1,074K**	**1,337K**	**1,142K**	**1,270K**	**5,738K**

Table 3-4. SIM Technology Workforce Plan

WBS Number	WBS Title	FY'97 Allocation (WY)	FY'98 Allocation (WY)	FY'99 Allocation (WY)	FY'00 Allocation (WY)
2BG51	ITP Management	3.5	3.0	3.0	3.0
	Accellarated SIM Tech for DS-3		10.9		
2BGXX	Generic & Long Range Technology	5.1	5.4	4.9	8.9
F0000	Instrument System Management/Reserve	0.0	8.0	6.1	6.0
	Sub-Total	8.6	27.3	14.0	17.9
FA000	Starlight Components	6.2	11.4	9.6	8.8
	Sub-Total	6.2	11.4	9.6	8.8
FC000	Metrology Components	4.8	4	2	0
FD000	MAM TB	5.4	6.5	6	1.2
	Sub-Total	10.2	10.5	8	1.2
FE000	Precision Structure Components	3.4	1.0	0.0	0.0
	Sub-Total	3.4	1.0	0.0	0.0
FF000	Real Time Interferometer Cont.S/W	4.0	10.4	9.1	5.2
F2000	System Eng. and V&V	0.0	4.8	7	10.6
F4000	SIM Testbed (STB-3) I&T	0.0	1.2	4.8	4.8
F5000	SIM Testbed (STB-1&2) I&T	5.0	5.0	3.0	1.1
	TOTAL	37.4	71.6	55.5	49.6

3.2.9 *Procurement Plan*

Table 3-5 below is the ITP Procurement Plan identifying all major procurements by WBS element and funding obligation date per current ITP schedule.

Table 3-5. SIM Technology Procurement Plan

WBS Number	WBS Title	FY'97 Procurement ($k)	FY'98 Procurement ($k)	FY'99 Procurement ($k)	FY'00 Procurement ($k)	Total Procurement ($k)
2BG51	ITP Management	368.0	750.0	316.0	415.0	1849.0
2BGXX	Generic & Long Range Technology	30.0	29.0	20.0	20.0	99.0
F0000	Instrument System Management	0.0	84.0	85.0	85.0	254.0
	Sub-Total	398.0	863.0	421.0	520.0	2202.0
FA000	Starlight Components	130	1638	438	202	2408.0
FC000	Metrology Components	435	453	874	10	1772.0
FD000	MAM TB	471	603	255	45	1374.0
	Sub-Total	906	1056	1129	55	3146.0
FE000	Precision Structure Components	283	242.0	403.0	0.0	928.0
	Sub-Total	283	242.0	403.0	0.0	928.0
FF000	Real Time Interferometer Cont.S/W	168.0	197	290	244	899.0
F2000	System Engineering and V & V	0.0	8	11	11	30.0
F4000	SIM Testbed (STB-3) I&T	0.0	0	484	813	1297.0
F5000	SIM Testbed (STB-1&2) I&T	242.0	347.0	387.0	0	976.0
	TOTAL	2127.0	4351.0	3563.0	1845.0	11886.0

3.2.10 Management Plan

3.2.10.1 Management Organization

The ultimate responsibility for the technology development for SIM resides with the ITP Program Manager. The SIM Project Manager and ITP Program Manager work through the SIM Instrument Manager with a single interferometry instrument team through various phases of the program. This allows synergism and synchronization between the technology development effort and the flight project design effort. The key implementation positions are the SIM Instrument Manager and the PEMs who report to him. The SIM Instrument Manager is responsible to the ITP Manager for implementing the SIM-specific portion of ITP. **Figure 3-3** identifies the ITP organization chart and its relationship to SIM Project. Note that the interface with NASA HQ, for both the SIM Project and ITP, is the Origins Program Manager. ITP funding is provided by HQS to the Space and Earth Science Programs Directorate (SESPD) and then suballocated to the Technology and Applications Program Directorate (TAP).

3.2.10.2 Roles and Responsibilities

The ITP Program Manager will be responsible for defining and negotiating the overall technology program implementation approach and, via subordinate task managers such as the SIM Instrument Manager, implementing the agreed upon approach within allocated cost and schedule. The ITP Program Manager will also be responsible for long-range interferometer technology planning, as well as for communicating program status to appropriate JPL management offices and NASA Office of Space Science. The SIM Instrument Manager and his PEMs are responsible for implementing the SIM unique tasks within agreed upon cost, schedule and technical guidelines. The ITP manager through his task managers is responsible for implementing the Generic and Long Range interferometer technology tasks. The PEMs and task managers will also interface with line organization to obtain personnel and facility resources to accomplish their respective tasks.

Interferometry Technology Program (ITP) Organization Chart

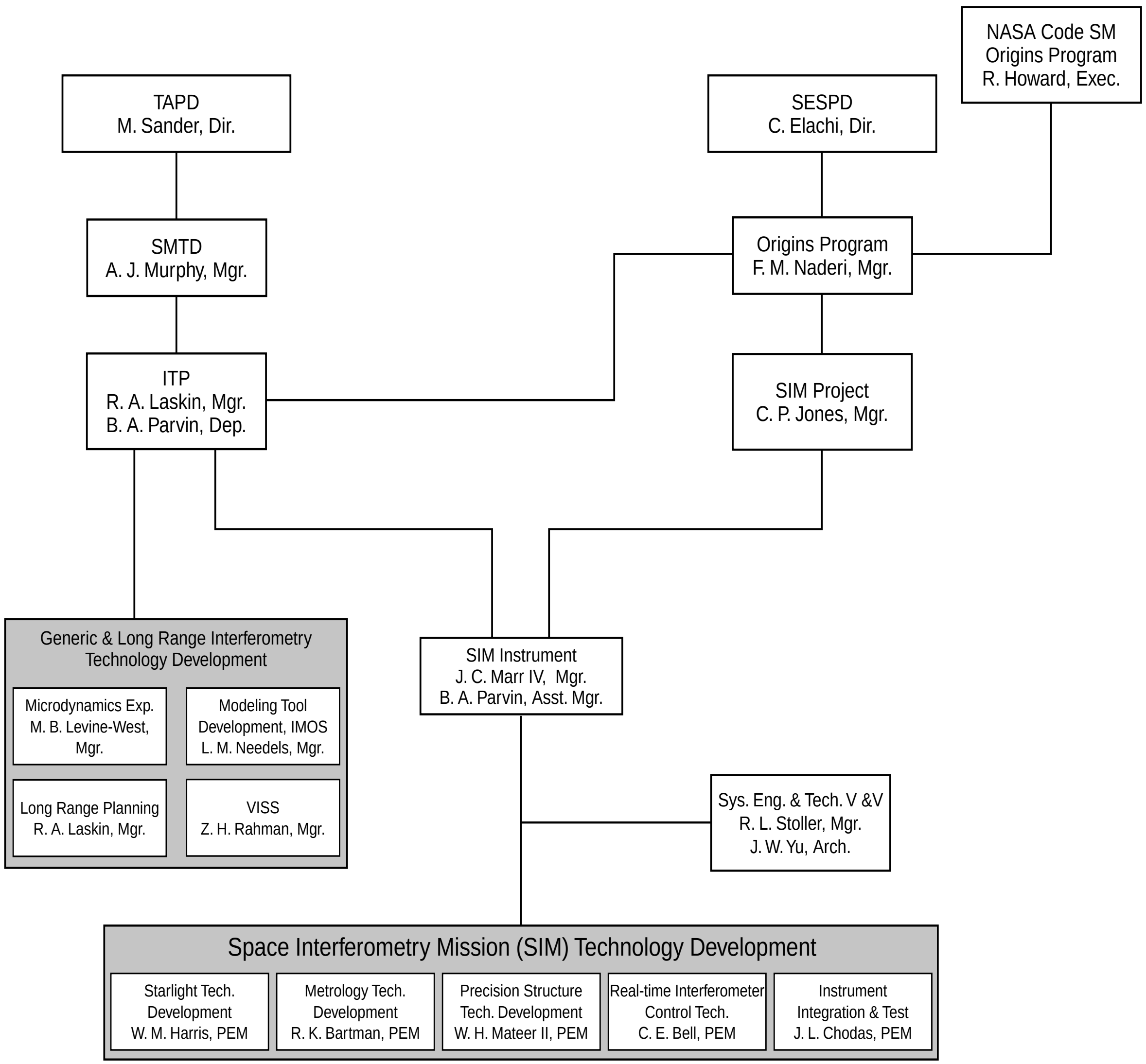


Figure 3-3. ITP Organization Chart

3.2.10.3 Reporting

The format and timing of the reports to NASA will be subject to the approval of the Office of Space Science. Integrated Program Master schedules, with identified critical paths will be established and will be maintained. Cost performance and planning tools shall be used to provide accurate monthly status of funds expended versus plans. This information will be integrated into a monthly report for transmission to NASA.

Weekly teleconferences will be held between the ITP Program Office, SIM Project Office, and the NASA Origins Executive to communicate status and resolve any issues which may arise. An annual state of the Program briefing will be prepared by JPL for presentation to the Office of Space Science. This briefing will take place in the Spring of each year as part of the status of Origins annual report.

Weekly Status Reports will be prepared by the ITP Program Office based on the weekly Status Reports from PEMs to the Program Office. This report will be distributed to the related JPL project and line managers and NASA Origins Executive.

3.2.10.4 Reviews

The SIM Project Office will appoint a Standing Review Board (SRB), comprised of experienced individuals from JPL, industry and academia to serve as the review agency for major reviews. The SRB chairperson will be responsible for preparing a report on the board's findings for each review to the JPL Origins Program Manager, who will in turn report the assessment and disposition of recommendations to the NASA Origins Program Executive.

The SIM Project Office in conjunction with ITP will appoint a Technical Advisory Committee (TAC), composed of experienced individuals from JPL, industry and academia to serve as an informal review function of technical progress for the Project and Technology Program. The TAC will meet approximately once every 6 weeks and will be responsible for PDRs, Critical Design Reviews (CDR) and critical technical issues for various subsystems and elements of SIM and ITP.

The SIM Project in conjunction with ITP will hold a Monthly Management Review (MMR) on the first Tuesday of each calendar month to review the overall program status and individual project's accomplishment, schedule and cost status versus plans. The MMR is intended to inform and identify problem areas which may require management actions.

3.2.10.5 Program Documentation

The ITP Program shall provide both management and technical documentation of its activities throughout the program life cycle. **Table 3-6** is a list of all the formal documents to be released by ITP.

Table 3-6. SIM Technology Documents

Item	Document Title	Release Date
1	SIM Technology Plan	January 15, 1997
2	System Engineering, Technology V&V TIP	March 15, 1998
3	SIM STB-1&2 TIP	April 15, 1998
4	SIM STB-3 TIP	April 15, 1998
5	Starlight Component TIP	April 15, 1998
6	Metrology Component TIP	April 15, 1998
7	Microarcsecond Metrology Testbed TIP	April 15, 1998
8	Precision Structure Component TIP	April 15, 1998
9	Real Time Control Testbed TIP	April 15, 1998
10	ODL Brassboard Document	October 1, 1997
11	Beam Launcher Brassboard Document	June 15, 1998
12	Beam Combiner Brassboard Document	June 15, 1998
13	Metrology Source Brassboard Document	June 15, 1998
14	Siderostat Bay Brassboard Document	September 15, 1999
15	Detector Brassboard Document	December 15, 1999
16	RICST S/W Management Plan	May 15, 1998
17	RICST S/W Requirement Document, Level 4	March 1, 1998
18	RICST S/W Design Specification Document, Level 5	July 1, 1998
19	RICST S/W Release Description Document V 1.0	October 1, 1999
20	MAMTB CDR Design Document	April 15, 1997
21	MAMTB W/A Performance Report	March 12, 1999
22	MAMTB W/A Performance Report	July 27, 1999
23	STB-1 Performance Report	September 15, 1998
24	STB-2 CDR Design Document	May 6, 1998
25	STB-2 Performance Report	September 20, 1999
26	STB-3 CDR Design Document	April 5, 1999
27	STB-3 Performance Report, 10 nm	October 16, 2000
28	STB-3 Performance Report	January 15, 2001
29	IMOS User Guide Ver. 3.0	January 15, 1998
30	IMOS User Guide Ver. 4.0	August 2, 1998
31	IPEX-1 Data Analysis Report	October 1, 1997
32	IPEX-2 Acceptance Data Package	July 15, 1997
33	IPEX-2 Data Analysis Report	September 15, 1998
34	Microdynamics Ground Data Analysis Report	September 15, 1999

3.2.10.6 Risk Management Plan

The Risks shall be identified by each element of the WBS in their respective TIP. The TIP shall identify the type of Risk that needs to be addressed for the Task by category: technical, schedule, and cost. A descope plan shall be summarized for each category by fiscal year.

ITP management will develop a technology development risk matrix to facilitate its decision making process for risk mitigation based on schedule, cost and technical guidelines during the implementation life of the program.

The technical risk in hardware development is mitigated by getting all critical disciplines, including reliability, involved in the design and development process of breadboards and brassboards from inception. Furthermore, the rapid prototyping used to build the breadboards and brassboards will quickly identify the critical design issues for sharper focus and analysis. Similarly, the technical risk in software development is managed by a rapid prototyping incremental development process interleaved with component development. This incremental development relies heavily on frequent peer reviews of requirements, design and code as its primary debugging tool, allowing significant elimination of defects prior to integration with actual brassboard components for final testing and debugging. A total of eight increments would have been completed and tested with hardware prior to release of version 1.0.

The schedule risk will be managed by planning ITP resources in such a way to have the implementation and the performance testing of the testbeds completed long before SIM Project required need dates. An example would be the two month of schedule reserve between the completion of STB-3 performance testing and NAR/PDR for the SIM Project.

3.2.10.7 Reserve Management

Each fiscal year, ITP management will set aside approximately 10 percent of its total budget as reserve. Most of the reserve will be allocated to the SIM Instrument Manager to cover unforeseen expenses deemed critical to maintaining schedule and meeting SIM derived technology performance requirements. An additional small reserve will be held for scope changes and unanticipated “targets of opportunity.” This reserve will be allocated by the ITP manager upon concurrence of the SIM Project Office. Adequate reserve will also be maintained to be used as carry forward into next fiscal year to support work force salaries for a period of 6 weeks.

A. Acronyms and Abbreviations

AF/PL	Air Force Phillips Lab
ASO	Astronomical Search for Origins
Astro	astronomical
B/C	beam combiner
B/L	beamlauncher
BMDO	Ballistic Missile Defense Organization
CCD	Charge-Coupled Device
CDR	Critical Design Review
CIT	California Institute of Technology
Cont. S/W	control software
Crista	Cryogenic Infrared Spectrometer and Telescope for the Atmosphere
DARA	Deutsche Agentur fuer RaumfahrtAngelegenheiten
DLI	Dilute Lens Interferometer
DoD	Department of Defense
DS-3	Deep Space-3
F/M	frequency modulator
F/Sh	frequency shifter
FMI	Focus Mission Interferometer
FSM	Fast-Steering Mirror
FST	Flight System Testbed
FSW	flight software
FTE	full-time employee
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
GSU	Georgia State University
H/W	hardware
HiFi	high fidelity
HQ	headquarters
HQS	NASA headquarters, Code S
I&T	integration and test
I/O	input/output
II&T	interferometer integration and test
IMOS	Integrated Modeling of Optical Systems
IPEX	Interferometry Program Experiment
IRTC	Interferometer Real-Time Control
ISIS	Initial Space Interferometer System
ISRD	Instrument System Requirements Document
ITP	Interferometry Technology Program

JPL	Jet Propulsion Laboratory
LaRC	Langley Research Center
M&C	monitor and control
MACOS	Modeling and Analysis of Controlled Optical System
MAM	Microarcsecond Metrology
MAMTB	Microarcsecond Metrology Testbed
MATLAB	matrix analysis software, The Mathworks Inc.
METR	metrology
MIT	Massachusetts Institute of Technology
MMR	Monthly Management Review
N/A	not applicable
NA	Narrow Angle
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NASTRAN	Finite element modeling software
NGST	Next Generation Space Telescope
NMP	New Millennium Program
ODL	Optical Delay Line
OPD	optical path difference
OSI	Orbiting Stellar Interferometer
PDR	Preliminary Design Review
PEM	Project Element Manager
PISRR	Preliminary Interferometer System Requirement Review
PNAR	Preliminary Non-Advocate Review
POINTS	Precision Optical Interferometer in Space
PSRD	Project Systems Requirements Document
PSS	Precision Structure Subsystem
PTI	Palomar Testbed Interferometer
RFP	Request for Proposal
RICST	Real-time Interferometer Control Software Testbed
RMS	Root Mean Square
RTC	Real Time Control
S/S	subsystem
S/W	software
SBIR	Small Business Innovative Research
SES	Space and Earth Science
SESPD	Space and Earth Science Programs Directorate
SIM	Space Interferometry Mission
SINDA	Systems Improved Numerical Difference Analyzer and Fluid Integrator, Lockheed-Martin

SIRTF	Space Infrared Telescope Facility
SMTD	Space Mission Technology Development
SPAS	Shuttle Pallet Satellite
SRB	Standing Review Board
STB	system testbed
STLT	starlight
STRV-2	Space Technology Research Vehicle-2
STS-80	Space Transport System-80
TAC	Technical Advisory Committee
TAP	Technology and Applications Program Directorate
TCA	Technology Cooperation Agreement
TIP	Task Implementation Plan
TPF	Terrestrial Planet Finder
TRASYS	Thermal Radiation Analyzer System, Lockheed Engineering and Management Services Company
V&V	validation and verification
VISS	Vibration Isolation Suppression and Steering
WA	wide angle
WBS	Work Breakdown Structure
WF	workforce
WY	work year